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MANUAL FOR METHODS OF QUICKLY VEGETATING SOILS OF LOW PRODUCTIVITY, CONSTRUCTION ACTIVITIES

MIDWEST RESEARCH INSTITUTE

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ENVIRONMENTAL PROTECTION AGENCY

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MRI REPORT

MANUAL FOR METHODS OF QUICKLY VEGETATING SOILS OF LOW PRODUCTIVITY, CONSTRUCTION ACTIVITIES

FINAL REPORT

EPA Contract No. 68-01-2632
MRI Project No. 3954-C

5 June 1975

For

Environmental Protection Agency
Office of Water Programs
Applied Technology Division
Waterside Mall, East Tower Room 2817D
401 M Street, S.W.
Washington, D.C. 20460

Attn: Mr. Robert E. Thronson
Project Officer

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Three additional short-term consultants provided successful and specific field documentation on establishment of vegetation on construction sites. These men were: Dr. Roy E. Blaser, Professor of Agronomy for Virginia Polytechnic Institute and State University; Dr. William A. Berg, Associate Professor of Soil Science for Colorado State University; and Mr. Burgess L. Kay, Specialist in Wildland Seeding, Department of Agronomy and Range Sciences, University of California.

SUMMARY

The Environmental Protection Agency is issuing this manual on "Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities," to assist the user in establishing protective stands of perennial vegetation on soils disturbed by all types of construction activities. The vegetative cover will prevent sediment runoff and thus minimize water pollution.

To quickly establish good vegetative cover on any soil of low productivity, one must know the climate; geological identification of parent material and the characteristics of the overlying soil; the biological factors of seed and plant selection, fertilizing, seedbed preparation, timely seeding, mulching, and perhaps irrigating. Establishment of vegetation can be most successful when conditions for plant growth are considered during the planning, designing, and construction stages of all soil-disturbing activities.*

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* Note: This manual will supplement information already issued under requirements of Section 304 (e), (2), (C) of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500).

I. AN INTRODUCTION TO THE MANUAL

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I. AN INTRODUCTION TO THE MANUAL

This manual was prepared for use by planners, engineers, and resource managers who want to provide for the rapid establishment of vegetation on low productivity soils that have been disturbed by construction activities. Gullies, muddy water, and sediment deposits near construction areas attest to the need for such protective vegetative covers. Finished slopes quickly erode unless stabilized by vegetation (Figure 1).

Luxuriant vegetation is perhaps the best way to protect soil surfaces. Areas of low soil productivity exist, however, that will not readily support dense vegetation because of low rainfall, low temperatures, steep or unstable slopes, soils of low inherent fertility, or toxic soil conditions. When these particular conditions occur, technology must be applied with more precision before a successful stand of vegetation can be achieved.

The planner often has a limited knowledge of the technology essential for the establishment of vegetation. Resource information given here is intended to help him by providing guidelines which have a high potential of success when applied.

A. Scope

The manual is principally concerned with the establishment of vegetation on construction sites where soils are infertile or of low productivity, and which thus present an especially difficult challenge to prevent sediment runoff.

It is quite apparent that vegetation can be successfully established only if certain minimum site requirements are met and that success can be achieved much more readily if the minimum requirements are exceeded. For these reasons, this manual presents minimum standards that define the least favorable allowable site and/or soil condition which is judged to be acceptable for establishment of vegetation. The functional purpose of this vegetation is to protect, quickly as well as permanently, the exposed soil surfaces against erosive and mechanical deteriorations.

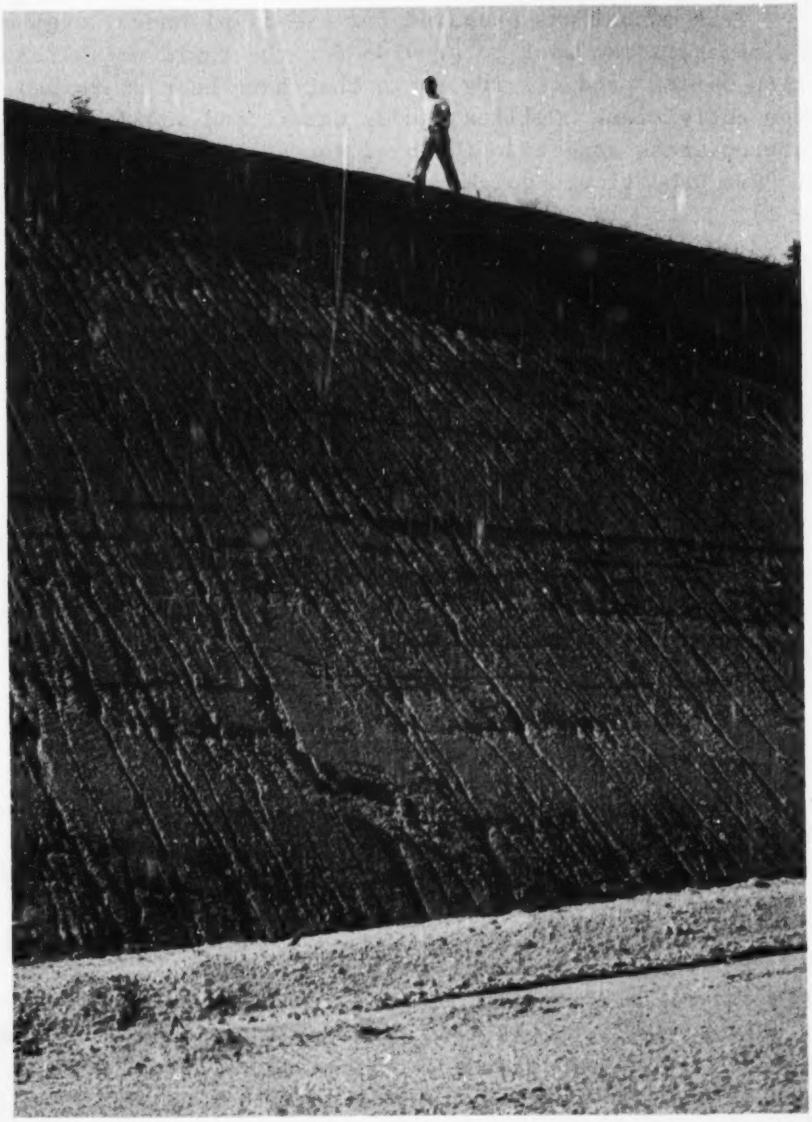


Figure 1 - Rill Erosion on a Finished Slope in Virginia is Representative of the Problems of Soil Surface Stabilization on Construction Sites (Courtesy of Roy Blaser)

It is self-evident that a construction scar covered with vegetation is more pleasing to the eye than one that is actively eroding or gullied. This manual does not explicitly deal with aesthetics; however, this parameter cannot be ignored. Planning for aesthetics does not interfere with functional protection of soil surfaces. The manual encompasses all construction sites within the 50 states on which erosion-preventing vegetation cannot be quickly and permanently established without resorting to special methods or procedures. It does not deal with the construction site having fertile and productive soils, in which vegetation can be readily established by standard procedures and maintained without resort to special measures. In this instance the planner need go no further than easily identifiable local authorities, including the engineering/construction companies, to obtain suitable erosion and sediment control plans and specifications. The restriction of this manual to nonproductive soils poses the requirement that nonproductivity (or infertility) be defined, a task which will be dealt with later in this section and in Section III. At this point it is appropriate to further restrict the manual to soils which are infertile but which can be transformed to a state of productivity by appropriate measures, which either have a permanent result or which achieve permanency (of fertility) by periodic renewal procedures.

The scope of the manual explicitly covers the types of vegetation that are capable of attaining a stage of maturity and ground coverage within one growing season which will be an effective deterrent to erosion and transport of sediments. Full maturity and complete (or permanent-state) coverage is expected within two to three growing seasons. In many instances these conditions may be best met with combinations of rapidly maturing annuals and more slowly maturing perennial vegetation, the latter providing the permanent or long-range protection. Grasses and legumes are the principal types of vegetation considered for construction site stabilization. At many construction sites, shrubs and trees are essential ingredients of soil stabilization. When planted alone, these have little value in the short term for erosion control, but can be of great and lasting value in the long term.

B. Depth and Detail of Coverage

The reader is forewarned not to expect to find a ready-made, detailed solution of his specific site problem in this manual, although the supporting documentation presented in Section IV will come close to providing a detailed solution for many similar situations. The reader should instead look for guidelines which are generally applicable; for a general approach and analytic/planning methodology which he can use to assure himself that no important factor has been neglected; for a rather limited but useful amount of specific information on adapted and native plant species, seedbed preparation, planting methods, soil modification procedures, equipment, and soil surface stabilization; for a necessarily concise discussion in a semitheoretical vein of the technology which applies to management of problem soils and establishment therein of vegetation; and above all, for sources of needed specific information, ranging from publications through agencies, universities, laboratories, and individuals within these organizations.

There are several very good reasons for avoiding the presentation of detailed solutions. First and foremost, innumerable "best" solutions would be needed to deal effectively with the entire country. Second, such research developments as new plant species tend to outdate the current detailed solutions. There is also new technology being developed that is available. Lastly, active involvement by experienced persons in the planning process at the local level is perhaps the best assurance of success. The manual is by no means offered as a substitute for local experience and judgment, but rather to supplement and reinforce.

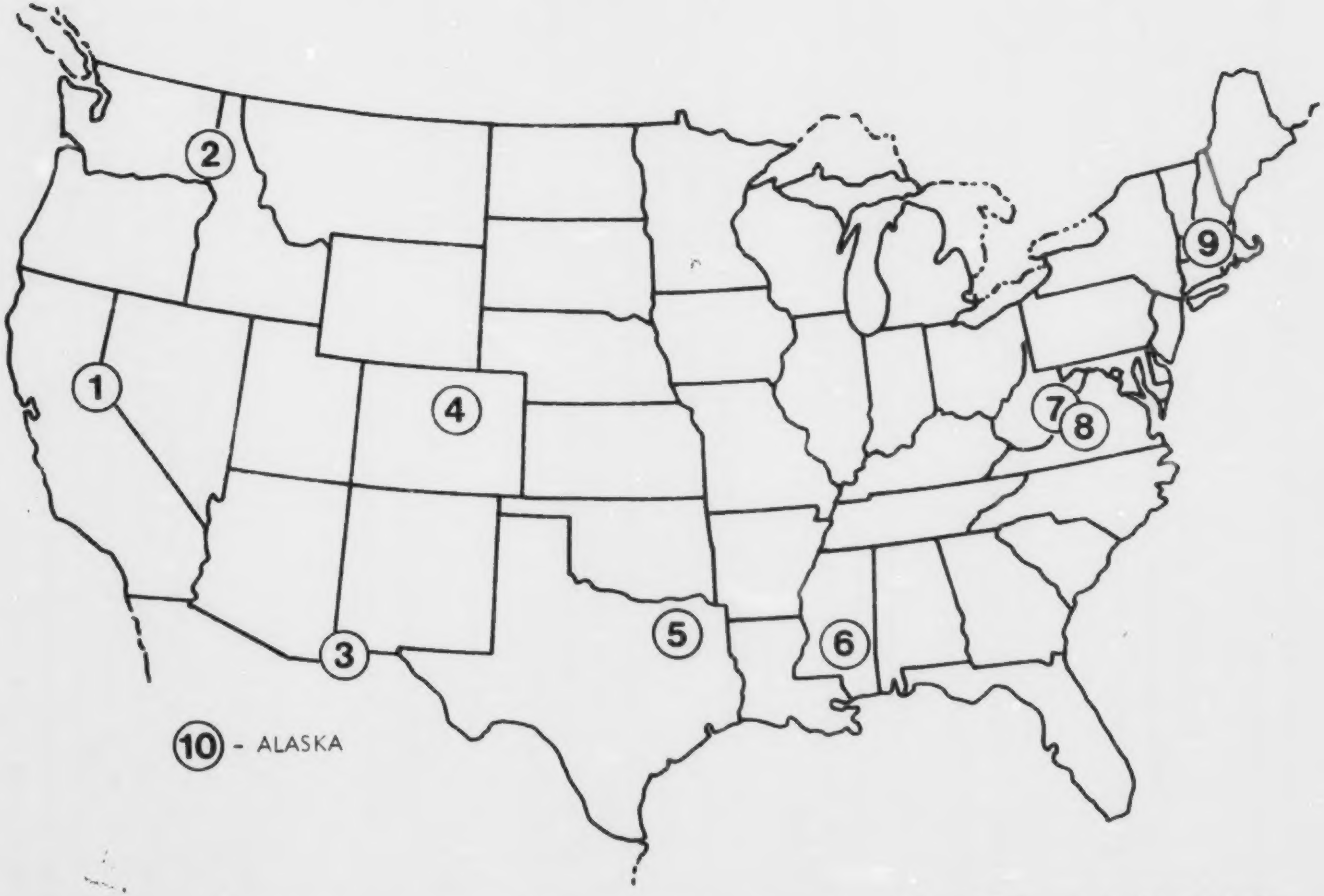
The manual does present, however, 10 detailed case studies (Section IV) which apply to more than one-third of the United States land area. These "demonstrations" are intended to be used as guideline documentation of basic technology and procedural methodology, and as sources of specific information on adapted plant species for a particular part of the country, problems peculiar to a region, and situation examples. The reader will benefit from reading all the case studies: the problems and their solutions differ in detail throughout the country, but the approaches to problem definition and the foundation technology are remarkably constant from one part of the country to the next. This lesson is a singularly valuable output of the case studies (Figure 2).

C. Characterization of Soils Low in Productivity

Soils may be low in productivity for one or more of several reasons:

1. Lack of plant nutrient elements, principally nitrogen, phosphorus, and potassium in available forms. If other factors are favorable, this soil deficiency can be readily corrected.

2. Lack of secondary or micronutrients. This problem can also be corrected but is more difficult to identify.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10 - ALASKA

Figure 2 - Map of the United States Showing the Location of the 10 Demonstration Areas

3. Soil pH--too alkaline or too acidic. A soil defect that can be readily corrected in most cases, with difficulty in some cases, or only with repeated treatments in isolated cases.

4. Low organic content. A rootbed deficiency which can usually be corrected.

5. Unfavorable soil conditions. There may be too much sand to retain adequate moisture or too much clay that has been compacted by heavy machinery. Such conditions can be corrected, but costs may be high.

6. A high water table caused by inflow of water from slopes or springs. Local drainage ditches can usually be constructed to alleviate the problem.

7. Unfavorable aspect. Direction of slope will influence field exposure to sunlight, soil moisture regime, and frost hazard which cannot be corrected. Suitable plant species must be selected for aspect conditions.

8. Unfavorable climate--insufficient moisture, short growing seasons, or perhaps extremes of temperature. There may be a need to start seedings with supplemental irrigation, for mulching to conserve moisture, or for careful timing in planting to take advantage of seasonal moisture. In addition, adapted plant species must be selected that can withstand extreme ambient hot or cold temperatures or short growing seasons.

9. Toxicity conditions other than acidity/alkalinity, e.g., too high a concentration of selenium, boron, or total soluble salts. This can be difficult and expensive to correct, but is relatively uncommon. Adapted plant species will accommodate moderate toxic conditions.

Soils classified as low in productivity are all soils which will not, in the absence of substantial remedial treatment, support both the rapid establishment and adequate maintenance of vegetative cover. "Substantial" is defined as treatment in excess of normal area practice for establishment of turf (or other vegetation in question) in topsoil typical of the area. In some areas, turf can be established successfully in normal topsoil only if measures beyond normal liming and fertilization are taken; such areas, for purposes of this manual, are considered to be low in productivity.

The undisturbed topsoil at a construction site will normally possess the inherent productivity typical of the region, subject to the variations caused by such factors as the specific slope of the site and its aspect, and the recent cultural background (natural forest, prairie, or recently exploited farmland, fallow land, or productive farmland). A topsoil may not, without substantial corrective measures or modification, support the dense cover and root systems needed to protect the construction site surface from erosion. If such is the case, the topsoil is properly considered to be low in productivity.

Subsurface soil materials (parent materials), which are usually below a depth of 2 m (6 ft), tend to be deficient in nitrogen and organic matter. They can generally be expected to be less than ideal from a nutrient standpoint and physically unsuitable for sustaining plant growth. Seldom will subsurface materials provide an adequate environment for plant growth, and as a result, they usually will be classed as infertile or nonproductive soils.

Extremely rocky soils will, in most instances, be viewed as permanently infertile unless the rocky surfaces are covered with fertile topsoil or with infertile earth material that can be treated. Soils in arid areas are properly classed as not productive, even though the lack of productivity may be principally caused by a low rainfall. They are considered in this manual only where supplemental irrigation is possible to start new seedings or where seasonal moisture is available to germinate the seeds.

D. Operating Assumptions

Unless otherwise specified, the following preconditions are assumed in this manual: construction slopes are no steeper than 2:1 (27 degrees, 50%) and have been designed for stability; surface and ground water is controlled, and the slopes can be made suitable for rapidly establishing vegetation. It is also assumed that no toxins are present to preclude plant growth; no fires will destroy the mulch; no wild animals or domestic animals will overgraze the plantings; and man will not destroy the established vegetation with motorcycles, snowmobiles, automobiles, or by trampling with the feet.

E. How to Use the Manual

As stated earlier, the manual has been developed primarily to serve the needs of planners, engineers, and resource managers. These individuals have several needs, which vary, but may include all of the following:

1. A management planning checklist or system which provides a formal mechanism to make sure that all important aspects of the problems have been covered. This system should include analyses which may be needed prior to selecting a specific construction site, for development of the site, and for planning for establishment and maintenance of vegetation.

2. Information sources such as:

   a. Professional expertise in appropriate areas; soil sciences, plant sciences, erosion control/water control, landscape planning and management.

   b. Laboratories for soil nutrient analysis.

   c. Publications, agency reports, and other documentation on subjects such as: (1) soil and geologic information; (2) compendia on adapted plant species; (3) climatic factors; rainfall and temperature by season; (4) seedbed preparation, fertilization, seeding, and mulching; (5) equipment; and (6) plant maintenance; irrigation, fertilization, pest control, periodic harvesting, mowing or spraying for weeds, and reseeding.

   These sources of information are cited liberally throughout the remaining sections of the manual, and are centrally listed in Section V.

3. A rudimentary background in the scientific technology of plant propagation. This manual is constructed to provide that need; and in addition, to supply references to numerous publications which treat specific subjects in detail. Sections III and IV in particular will be useful to the reader in this connection.

4. Examples of vegetative establishment presented in sufficient detail to tailor a course of action patterned after plans which have succeeded, whether the details of the exemplary plans specifically match his needs or not. These examples are presented in Section IV.

The user of this manual is advised now to proceed approximately as follows:

a. Consult Section III first to gain a general education in the science of soils in relation to propagating vegetation under difficult circumstances.

b. Evaluate the documented examples of successful establishment of vegetation in Section IV.

c. Use Section II to develop methodology for evaluating and analyzing the problem or situation which must be specifically dealt with, determine needs, and prepare a general plan for vegetation.

d. Develop a detailed plan, using Section II, for planting the site and maintaining the vegetative cover.

e. Where information is lacking, or needs additional support, consult Section V.

II. PRACTICAL PROCEDURES FOR ESTABLISHING AND MAINTAINING VEGETATION

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II. PRACTICAL PROCEDURES FOR ESTABLISHING AND MAINTAINING VEGETATION

A. Introduction

Vegetation for erosion and sediment control purposes should be an integral part of planning and design phases for all earth construction activities. At each new site, variations in weather, topography, and soil and geologic materials govern the options available for the successful establishment of plants. Basic steps, however, can be formulated.

Some materials, such as shifting dune sands, hard rock surfaces, alkali soils, permanently frozen tundra, desert areas, or rapidly eroding soils, do not readily support the soil-binding plants. On steep slopes such materials may have to be held in place with mechanical structures such as concrete retaining walls or asphalt or stone blankets. Sites that are marginal for stabilizing with vegetation alone can be successfully held in place by a combination of mechanical and vegetative practices.

Plants have their limitations. Many grasses have a shallow root system and are for that reason not effective in preventing surface creep. Certain deep-rooted trees and shrubs must be planted on such sites. In contrast, most adapted grasses can quickly become established on stable slopes and will prevent more surface erosion during the first few years than can trees or shrubs.

Each species of grass, legume, shrub, or tree has its climatic, physiographic, and biologic limitation. Moisture, light, temperature, elevation, aspect, balance of essential nutrients, and plant competition are ecological parameters that favor or restrict all plant species. Each species selected for a particular site must therefore be adapted to all existing factors of the habitat, or man must so manipulate those factors to make them favorable. Examples of modifying the habitat to make conditions more favorable for specified plant species are the liming of acid soils and the fertilizing of infertile soils. Such manipulation of the site conditions will broaden the option of adapted plant species.

The following Section B gives a summary of the essential practices necessary for methodical planning. Nearly all practices mentioned will probably not apply to any given situation, but each step must be considered, rejected, or adapted for each site plan. Section C is a summary checkoff list of those factors involved in vegetation planning so that the use of plants can be effectively engineered into a construction plan to help prevent sediment pollution.

Section D is a general discussion concerning mulching materials and their application; Section E directs the user to Section V, Subsections K, L and M which gives practical procedures for soil test interpretations for lime, nitrogen, phosphorus, and potassium; followed by tables on seed and seeding data for plants recommended on construction sites in the 17 western States. As well as the most recent characteristics and seeding recommendations for grasses and legumes adapted to the midwestern United States. Section F lists additional references useful to those readers who need to search out more specific information.

B. Planning for Establishment of Vegetation

1. Essential practices involved in the planning process: General practices are presented here for establishing and maintaining vegetation on soils disturbed by construction activities.* These will be similar for comparable disturbed soils and parent materials, whether on interstate highways, forest roads, pipelines, urban developments, earthen dams, or recreation areas.

a. Minimum slope and surface requirements: Preconditions for vegetating soils of low productivity include, as a minimum, slopes that are:

- Generally no steeper than 2:1 (27 degrees, 50%);
- Designed for stability;
- Designed for control of surface and ground water; and
- Designed for quickly establishing vegetation.

---

* Specific documented examples are portrayed in Section IV for 10 selected demonstration sites that represent major ecological regions of the United States where the soils and geologic materials are especially difficult to vegetate.

b. Soil testing: Soil samples should be collected before construction begins according to State recommendations for physical and plant nutrient testing. Each field sample should represent a recognized contrast of soil-geologic material, and the sampling should extend horizontally over the entire proposed construction site and vertically to the depth of the material to be affected. Samples should represent material that will remain on the site. In areas of extensive disturbances, soil sampling may be done after completion of construction activities. All State highway departments have their own testing laboratories for physical testing; for nutrient testing, however, the agricultural laboratories of the State land-grant universities are available.

c. Clay or sand and organic matter intermixing: Based upon physical soil tests, it may be desirable to enhance the plant root environment by intermixing to a depth of 10 to 15 cm (4 to 6 in.) clay with sandy-skeletal materials, and sand with fine clay soils. Organic matter should then be mixed in amounts between 5 and 20% by volume. Organic matter may come from nearby peat or muck bogs, or its source may be well-rooted animal manures or composted sewage sludge.

d. Topsoiling: In most States, topsoiling at one time was a widely recommended practice. There is recent evidence, however, that on many sites there may be a cheaper alternative; i.e., the liming (if needed) and fertilizing according to a soil test of the existing intermixed material on the final grade, together with the incorporation of compost, well-rooted manure, or peat or muck. Scalping an adjacent field for topsoil is expensive as well as a waste of productivity for food and feed crops.

e. Liming and fertilizing: If called for by a soil test, lime should be added until the pH of the soil plant bed is at least 6, but no more than 7. The lime should be either drilled or broadcast and disked into the surface 10 to 15 cm (4 to 6 in.) and left for at least a week, or until one soaking rain is received. Fertilizers prescribed by the soil test should then be drilled into the surface 10 to 15 cm (4 to 6 in.) or broadcast and disked in.

f. Permanent seeding: Permanent seeding mixtures that are recommended by the agricultural experts in each State for the particular climate and soil should be drilled if the slope is flat enough, sown with a cyclone-type hand seeder, or, on steep and long slopes, mixed with a suitable mulch and sown with a hydroseeder. Seeding should be done as soon as the grading is completed and before rains create a surface crust (Figure 3).

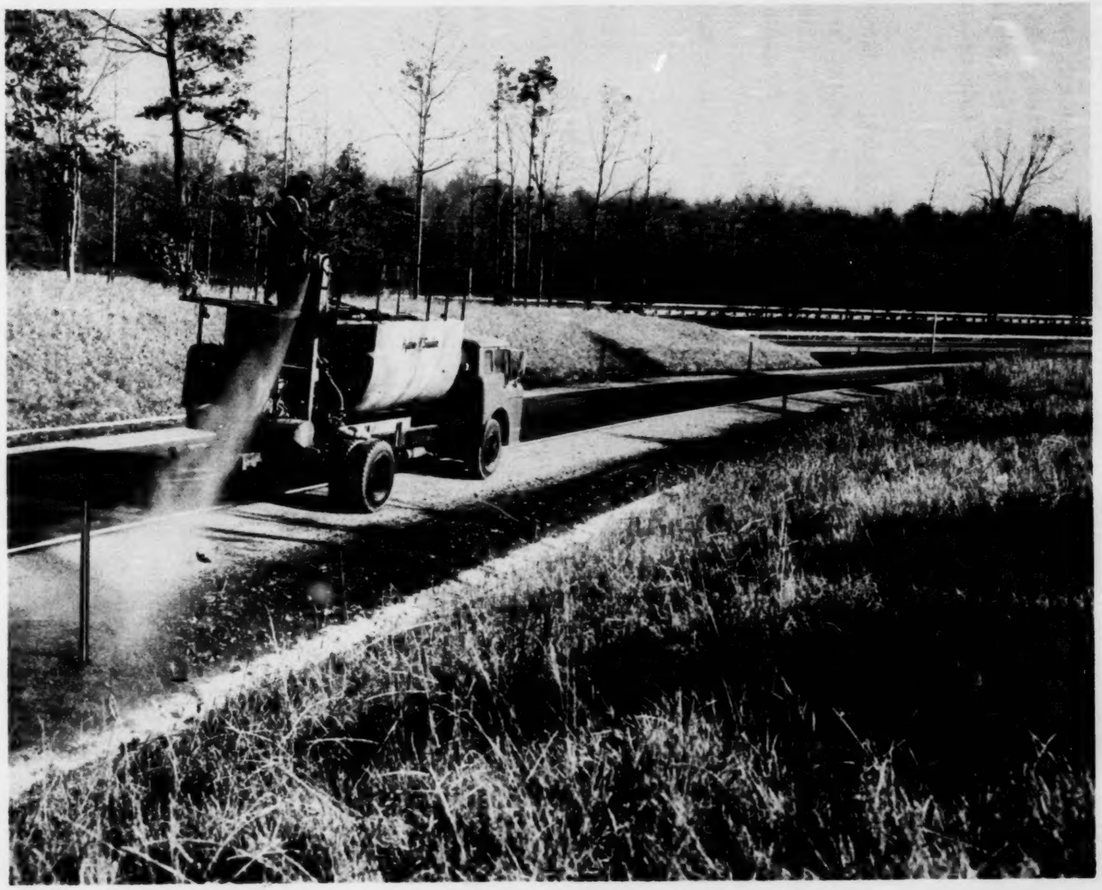

Figure 3 - A Seeding of Perennial Vegetation Should be Applied as Soon as Final Grade Has Been Established. Hydroseeders are useful to apply seed and mulch in a combined slurry in humid areas and especially on steep or stony slopes (Massachusetts). (Courtesy of Ken Soper)

g. Temporary seeding: Temporary seeding should be practiced when it is out of season for a permanent seeding mixture. Grain rye or annual ryegrass are the two most commonly used kinds of seeds for off-season seeding. When the season is proper, temporary seeding should be followed by a permanent seeding, as discussed in "Permanent Seeding."

h. Mulching: Mulching should be practiced in conjunction with either permanent or temporary seeding. The most common kinds of mulches used are grain straw, hay, woodfiber, and woodchips. Almost any organic material can be used as a mulch that is not toxic and that is the right physical condition. Animal manures are ideal if they are sufficiently well rotted and finely divided and do not smother the seedlings. Composted sewage sludge also can be used. Care must be taken not to apply animal manures or sewage sludge so heavily that runoff waters will pollute nearby streams. Asphalt, resins, and latex have been used as mulches but only when sprayed thinly on coarse-textured soils can they be used in conjunction with vegetation.

i. Sodding: Areas made critical because of steepness of slope or high runoff water velocities should be sodded.

j. Maintenance: Adequate maintenance of a permanent seeding must be determined by periodic inspection. Almost all seedings require mowing to permit sunlight to penetrate into the low-growing members of the mixture and to prevent smothering weeds. If no legumes are present, chemical herbicides may be used to control unwanted broad-leafed forbs, shrubs, and tree seedlings. An occasional insect infestation can be controlled by spraying a safe pesticide. On sandy soils in high rainfall areas, the established seeding may become thin and weak in spots and areas due probably to nitrogen deficiency; this condition can be corrected by topdressing with a fertilizer made according to another soil test (refer to Section V, Subsection K).

2. Guidelines for preventing sediment runoff with vegetation--a checklist for planning: Prior to the actual site selection and contract work on any construction job, there is usually extensive professional activity involving the careful review of site alternatives based on topographic surveys, soil profile borings, geologic and soil-bearing analyses, climate, transportation, utilities, and other details. After exhaustive engineering information gathering, the design plan will be developed. The potential and feasibility for effectively using vegetation to prevent sediment runoff can be assessed during this early site

selection and planning period. The effective use of vegetation will be enhanced by including conditions for selected plant growth into the finished construction design. Following is a checklist of design considerations that can influence the successful and long-term establishment of plants to protect graded soil surfaces.

Preconstruction Analysis

1. Judgemental analysis of site: Is it possible to vegetate the site?

( ) Observe existing plants
( ) Consider possible effect of construction activities

These conditions may not be practical to vegetate:

( ) Shifting dune sands
( ) Hard rock surfaces
( ) Extremely salty soil
( ) Permanently frozen tundra
( ) Some desert areas
( ) Steep, unstable slopes
( ) Rapidly eroding soil surfaces

2. Basic site information

( ) Geologic analysis from profile borings
( ) Topographic survey
( ) Soil survey of surface 2-m depth
( ) Weather and climate profile
( ) Water management problems, i.e., flooding, swamp, too dry, etc.

Planning

1. Characterize the plant environment for:

( ) Moisture, temperature, and storm patterns
( ) Rootbed environment of the cut, and other fill areas
( ) Topsoil materials
( ) Subsurface, or parent materials
( ) Soil acidity, available plant nutrients, and organic content
( ) Soil textural evaluation, moisture retention, and infiltration capacity
( ) Root-zone depth and material uniformity
( ) Aspect influence, i.e., temperature and moisture differences

2. Define plant characteristics

( ) Shallow root systems for surface soil protection
( ) Deep root system for soil binding
( ) Are warm soils needed
( ) Are cool soils needed
( ) Can they survive cold winters, hot summers, or long dry periods
( ) Are they slow or fast growing
( ) Survival duration: annual, biennial, or perennial
( ) What are the vegetation propagation characteristics
( ) Is maintenance necessary or required
( ) Density of cover
( ) Organic residue production for use as a mulch
( ) Height of plants for visibility, aesthetics, or fire hazard
( ) Adaptation to existing soil

3. Design of site to provide for establishment of vegetation

Alter plant habitat by modifying the conditions for specified plant species:

( ) Reduce slope grade
( ) Limit steepness of cut or fill slopes
( ) Provide for roughness on finished soil surfaces
( ) Control surface water runoff
( ) Cultivate the root bed
( ) Mulch the planting surface
( ) Stabilize slopes
( ) Irrigate seedings where necessary

4. Select vegetation

( ) Determine options for adapted plant species (which may be for a rather narrow range of conditions) throughout the site
( ) Establish a source of seed and/or plants for each species in the quantity or numbers required. (A contract nursery may need to grow the plants a year or more in advance of the seeding date.)

5. Determine the amount and kind of fertilizer, lime, and mulch required.

6. Plan for seed and rootbed preparation: Based on the site information and analysis, plan and specify all required modifications to the grade surface material to induce establishment of vegetation such as: alteration of the texture by mixing clay soil with a sand soil; or mixing sand into a clay soil; ripping and breaking up the underneath parent material to make an improved plant root medium; backfill with stockpiled topsoil or hauled-in topsoil.

7. Determine maintenance needed: Develop a long range procedural specification and schedule for all needed maintenance operations to include:

   - ( ) Control of soil erosion until vegetation is established
   - ( ) Mowing of grasses
   - ( ) Weed spraying
   - ( ) Fertilizing or liming
   - ( ) Reseeding
   - ( ) Replanting where required
   - ( ) Removal of sediment
   - ( ) Regrading or placing of fill on eroded surfaces

Implement Design Plan

1. Establish field management responsibility

   - ( ) During the construction phase
   - ( ) During the establishment of vegetation after construction
   - ( ) Make frequent field inspections after vegetation establishment until the vegetation has stabilized in soil

2. Establish management responsibility for the long-term care and maintenance of all vegetation on the site.

C. Engineering Design Planning to Control Erosion

It is important that the user of this manual realize how engineering design planning can hasten the establishment of a vegetative cover to prevent erosion and sediment runoff. The following guidelines are adapted from a summary of practices recommended by the Highway Research Board1/ to control erosion on highway construction projects.

1/ Highway Research Board, "Erosion Control on Highway Construction," National Cooperative Highway Research Program Synthesis of Highway Practice 18, Division of Engineering, National Research Council, National Academy of Sciences--National Academy of Engineering, pp. 27-28 (1973).

1. Preplanning for erosion control

a. Start erosion control planning with route selection.

b. Obtain stream data for a season or more prior to construction.

c. Select and incorporate appropriate measures during design.

d. Develop sediment collection plans during location and design.

e. Assure timely and correct establishment through guidelines, specifications, surveillance, and training.

f. Control by contract stipulations the maximum area of unprotected soil that can be exposed for each construction phase at any one time.

2. Field implementation of control plan

a. Make use of clearing and proposed grading lines to limit clearing and protect existing cover.

b. Reduce the duration of unprotected soil exposure by requiring stage seeding and mulching as work is completed.

c. Use materials from the project (i.e., brush, logs, chippings) to control erosion, filter sediment, and serve as a mulch.

d. Provide water management measures for sediment control from borrow areas, haul roads, fire-control breakers, and waste-disposal areas during use, with restoration after use (Figure 4).

e. Protect bodies of water and running streams from siltation with temporary measures such as berms, dikes, and sediment basins until permanent measures are effective.

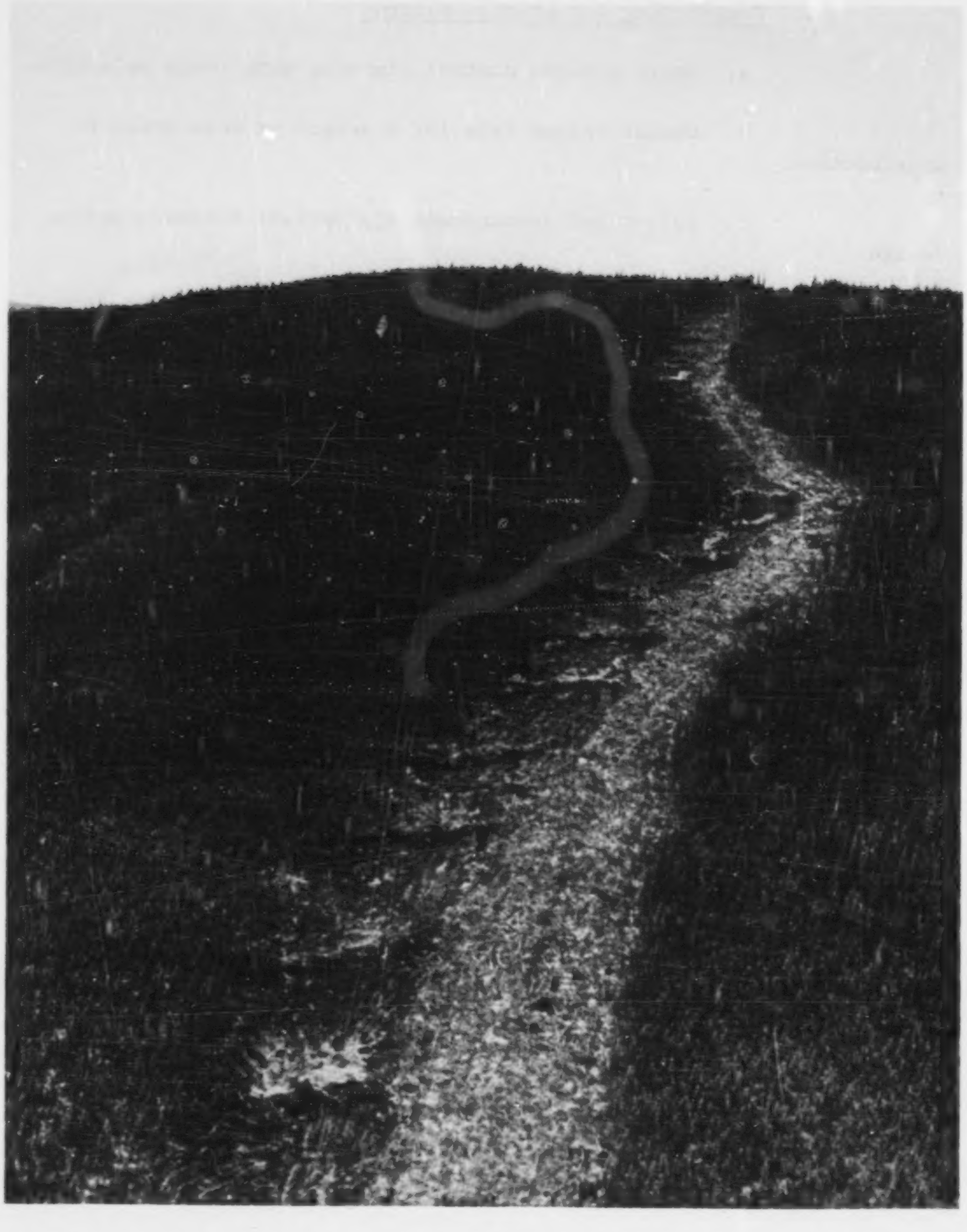

Figure 4 - Water Barriers Were Constructed Along This Firebreak to Control Erosion and Sediment (Courtesy of U.S. Bureau of Land Management)

3. Using vegetation in the engineered sediment control plan

a. Plan for temporary and permanent control of concentrated runoff from construction areas (sediment traps, vegetation filter barriers).

b. Provide protection at inlet and outlet ends of culverts, drainage channels, and other flow junctions, including adequate energy dissipators.

c. Convert intercepted surface runoff to sheet flow (level spreader) where there are stable discharge areas, such as woods, sod, rock, or concrete rubble.

d. Use flat slopes to maximize erosion control by vegetation.

e. Make liberal use of temporary seedings between construction phases when permanent seedings are out of season.

f. Be wary of using maximum permissible velocities in vegetated channels because few sods are maintained at maximum density by the usual fertilization and mowing practices.

g. Use adaptable mulches to the maximum consistent with the erosion hazard. Apply mulches as soon as possible in the construction sequence, using proven anchoring methods.

h. Anchor hay or straw into the soil, especially in areas of high winds.

i. Seed and mulch by segments of high cuts and fills.

j. Wherever possible, incorporate lime and fertilizers into the seedbed before seeding and mulching.

k. Provide for access to slopes where it is shown that maintenance practices have to be used to retain vegetation effectiveness.

4. Wind erosion control

a. Use slope grades of 10:1 to 20:1 on sand soils in areas where wind erosion is a problem.

b. Start the control of wind erosion at the field sources nearby, even if this means cooperative efforts by the highway agency, adjacent landowners, and conservation agencies.

c. Use native plant species to the greatest extent possible, especially in arid regions west of the Mississippi River. Use proven long-lived species requiring a minimum of maintenance.

5. Use of multidiscipline teams and applied research data

a. Use the design team approach for solution of complex erosion control measures and to spot training weaknesses.

b. Convert research data into simplified working tools.

c. Take full advantage of information and services available from other agencies with like concerns.

d. Develop and maintain contacts with the construction industry (e.g., contractor associations) to share problems and develop solutions.

6. Training and project documentation

a. Carry out inspections in-depth to point out training needs and to strengthen design.

b. Document events that occur during construction. Color slides can be most helpful if damage claims are presented.

D. Mulching

When constructed land surfaces have been brought to final grades, immediate protection must be provided to prevent physical damage from the erosive action of storm water and to control sediment pollution. Erosion from raindrop impact can be reduced immediately by the application of a mulch to cover and shield soil surfaces until a grass or grass-legume vegetative cover can be established. Mulching materials not only will reduce raindrop impact, but will encourage an increase in soil structure cohesiveness, an increase in water infiltration, a reduction in water velocity, a moderation of soil temperatures, slower evaporation of soil moisture, a reduction of surface soil crusting of the seedbed, and an on-site entrapment of silt.

Mulches can be most effective when water overland flows are controlled by engineering design. A reduction in water velocity can be accomplished by flatter cut or fill slopes, flatter gradients in drainageways, and by reducing effective slope length by diversion terraces. Erosion will be most rapid on unprotected cut and fill side slopes. It will be very difficult to place and hold even coarse organic mulch on slopes steeper than 2:1 (27 degrees, 50%). The slope angle must have been designed for soil bank stability, or slope failure in the form of landslides or excessive surface erosion will occur (Figure 5). The use of mulches cannot prevent a slide but only provides, at best, temporary surface protection until vegetation can be established. Among the many materials suitable for mulching, crop residues like straw and hay generally are the most available, economical, and commonly used. The standard is 1-1/2 to 2 tons of straw per acre, held in place by punching with a special roller or held in place by a net. A variety of wood residues, including woodchips, bark, excelsior, and cellulose fiber, are available as mulching materials. Several petroleum products, such as asphalt and resin-in-water emulsions, may be useful as mulches for establishing vegetation. Also available for special situations are plastic films, gravel, stones, manure, sewage sludge, excelsior, jute, peat, and paper. Selection depends on characteristics of the area to be stabilized and the availability, cost, and properties of the mulch material.

For example, investigations in New Mexico have shown the advantages of mulching for establishing perennial species. For summer seeding near Santa Fe, the most effective mulch material was wild grass hay, which reduced moisture losses and lowered midafternoon temperatures in the top inch of soil during the time seeds were germinating and seedlings emerging.

The Louisiana Department of Highways[1/] conducted research to evaluate chemical soil stabilizers for erosion control in that State. The essential study was in two phases, a field phase where available

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[1/] Law, S. M., and S. J. Vaccaro, "Erosion Evaluation Study," conducted by Louisiana Department of Highways in Cooperation with U.S. Department of Transportation, Federal Highway Administration, 49 pages, June 1974.

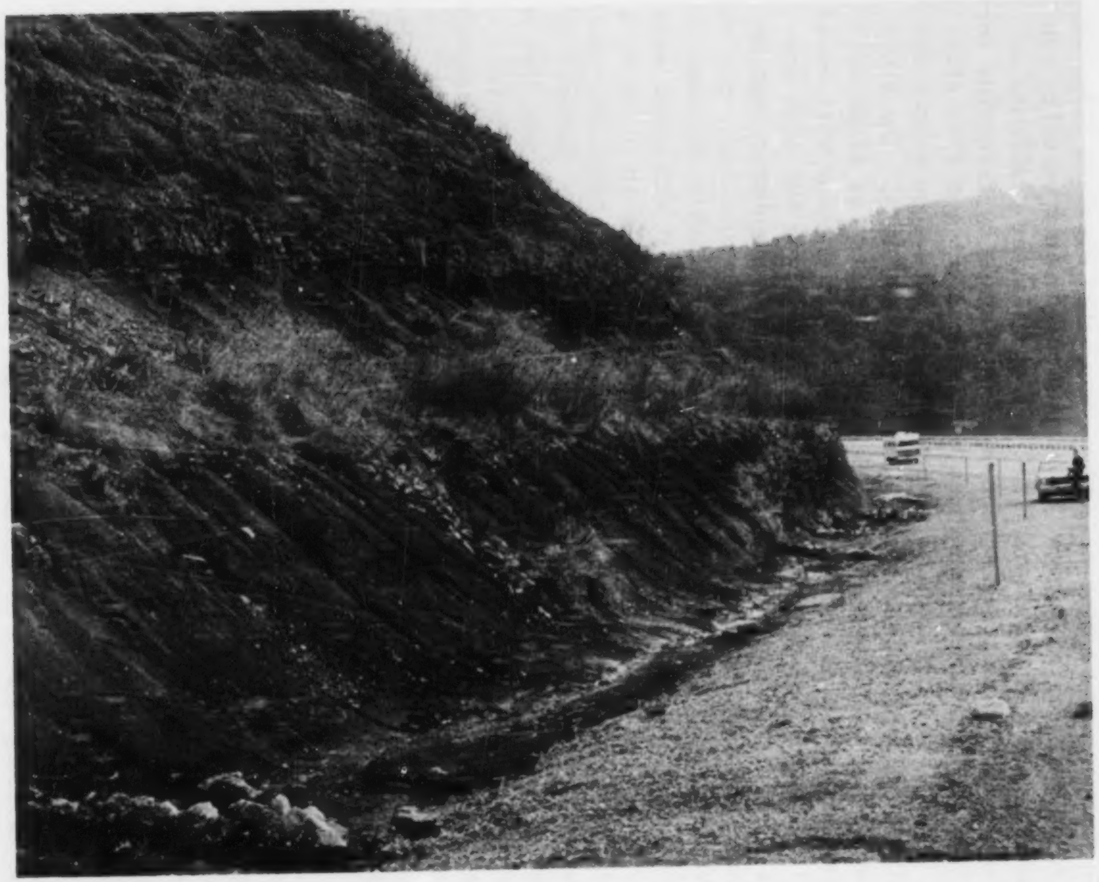

Figure 5 - Stabilizing Cut Slopes with Mulch and Vegetation Along Roadsides is Difficult Because of Unproductive Soils and Steep Slopes; in Places Stones Interfere with Rapid Establishment of Vegetation. The net result is rapid erosion and high sediment yield (West Virginia).
(Courtesy of Roy Blaser)

products were installed on selected test slopes located in northern Louisiana and observed, and a laboratory phase where the products were installed (as reported by Barnett et al.) on plots containing grass seed and fertilizer and observed to obtain seed germination data. This research included treated soil in test pans tested under a rainfall simulator to obtain comparative soil loss data. Two types of mulching product materials were used; wood fiber mulches and chemical soil binders or erosion retardants. The principal factors affecting the results obtained on this study in the field were the weather conditions, the size, shape, and steepness of the slopes and the types of soil present. Most of the slopes studied were fairly long and steep.

Two primary conclusions were: "There is only an observed general relationship between the field phase test results and the laboratory test results; however, the laboratory results bear out the field observations."

"Grass stand growth was slow in beginning on all field slopes; however, as shown in the laboratory results, all of the wood fiber mulches did well in seed germination and establishment of grass stand growth. The soil stabilizers were poor in this category generally."

Turn to Section V, Subsection J for more comprehensive information on the selection and limitations of mulching materials for stabilizing critical areas.

E. Other Practical Procedures

Additional practical procedures for soil test interpretation for lime and fertilizers and seed and seeding data and recommendations are presented in Section V, Subsections K, L, and M.

F. Additional References

Barnett, A. P., E. G. Diseker, and E. C. Richardson, "Evaluation of Mulching Methods for Erosion Control on Newly Prepared and Seeded Highway Backslopes," Agricultural Journal, 50:83-85 (1967).

Bertrand, A. R., and J. F. Parr, "Design and Operation of the Purdue Sprinkling Infiltrometer," Research Bulletin No. 723, Purdue University Agricultural Experiment Station, August 1961.

Briggs, W. M., "Inventory of Roadside Erosion in Wisconsin," HRB Special Report 135, Washington Highway Research Board, pp. 77-81 (1973).

Bubenzer, G. D., and L. D. Meyers, "Simulation of Rainfall and Soils for Laboratory Research," *Transactions of the American Society of Agricultural Engineers*, 8(1):73,75 (1965).

Goss, R. L., R. M. Blanchard, and W. R. Melton, "The Establishment of Vegetation of Nontopsoiled Highway Slopes in Washington," Washington State Highway Commission, Washington State University Agricultural Research Center, and the United States Department of Transportation, Federal Highway Administration, Cooperating Final Report, 29 pages (1966-1969).

Jonsson, G. B., et al., "Direct Seeding of Shrubs Along Roadsides in Massachusetts," Roadside Development Report 39-R-5-2656, University of Massachusetts, 10 pages (1974).

Mech, S. J., "Limitations of Simulated Rainfall as a Research Tool," *Transactions of the American Society of Agricultural Engineers*, 8(1):66,75 (1965).

Meyer, L. D., "An Investigation of Methods for Simulating Rainfall on Standard Runoff Plots and a Study of the Drop Size, Velocity and Kinetic Energy of Selected Spray Nozzles," Special Report No. 81, Purdue University Agricultural Experiment Station, May 1958.

Meyer, L. D., C. B. Johnson, and E. R. Foster, "Stone and Woodchip Mulches for Erosion Control on Construction Sites," *Journal of Soils and Water Conservation* (1972).

Meyer, L. D., and L. A. Kramer, "Relation Between Land-Slope Shape and Erosion," *Agricultural Engineer*, 50:522-523 (1965).

Meyer, L. D. and D. L. McCune, "Rainfall Simulator for Runoff Plots," *Agricultural Engineer*, 39:644-648 (1958).

Mutchler, C. K., and L. F. Hermsmeier, " A Review of Rainfall Simulators," *Transactions of the American Society of Agricultural Engineers*, 8(1):67-68 (1965).

Mutchler, C. K., and W. C. Moldenhauer, "Applicator for Laboratory Rainfall Simulator," *Transactions of the American Society of Agricultural Engineers*, 6(3):220-222 (1963).

National Association of Conservation Districts, "Suggested Guidelines and Standards for Erosion and Sediment Control Programs" (Texas).

Peters, J. D., F. S. Rostler, and B. A. Vallerga, "Promising Materials and Methods for Erosion Control," HRB Special Report 135, Washington Highway Research Board, pp. 105-117 (1973).

Plass, W. T., "Chemical Soil Stabilizers for Surface Mine Reclamation," HRB Special Report 135, Washington Highway Research Board, pp. 118-122 (1973).

Swanson, N. P., A. R. Dedrick, and H. E. Weakly, "Soil Particles and Aggregates Transported in Runoff from Simulated Rainfall," *Transactions of the American Society of Agricultural Engineers*, *8*(1):437,440 (1965).

Swanson, N. P., A. R. Dedrick, H. E. Weakly, and H. R. Haise, "Evaluation of Mulches for Water-Erosion Control," *Transactions of the American Society of Agricultural Engineers*, *8*(1):438-440 (1965).

Turelle, J. W., "Factors Involved in the Use of Herbaceous Plants for Erosion Control on Roadways," HRB Special Report 135, Washington Highway Research Board, pp. 99-104 (1973).

Wischmeier, W. H., and L. D. Meyer, "Soil Erodibility on Construction Areas," HRB Special Report 135, Washington Highway Research Board, pp. 20-29 (1973).

Zak, J. M., "A Handbook for the Selection of Some Adaptable Plant Species for Massachusetts Roadsides," Roadside Development Report No. 24-R5-2656, University of Massachusetts, 43 pages (1972).

III. FUNDAMENTAL TECHNOLOGY FOR ESTABLISHING AND MAINTAINING VEGETATION

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III. FUNDAMENTAL TECHNOLOGY FOR ESTABLISHING AND MAINTAINING VEGETATION

A. Introduction

Living organisms and their nonliving environments comprise the ecosystem.* Living organisms consist of chlorophyll-bearing plants, fungi, and animals including man. Not only do green plants manufacture food, they also hold the surface of the earth in place.

Plants and their organic remains have protected land surfaces for thousands of years. This protective cover is destroyed by all construction activities in which large acreages of soil and underlying geologic material are stripped of all living plants and organic matter and made bare and barren. The naked soil is compacted by machines; intermixed and moved to new sites; and often left exposed on steep and smooth cut slopes that resist wetting, or as raw fill slopes that slake and flow during the rains. This unprotected earth surface becomes a source of dust and sediment; it is also a more critical environment for reestablishing protective vegetation.

Science must be applied with precision and timeliness if plants are to be successfully reestablished on land surfaces that have been disturbed by construction activities. On the most critical areas, more research will be needed before vegetation can be used to stabilize the surface soil. In some areas of very low rainfall, high salt content, bedrock, steep slopes, compacted soils, or toxic minerals, no plants can be expected to grow without creating a new physical, chemical, and biological plant root environment. There are a few situations where it is more feasible to stabilize the surface of construction sites by engineered structures than with vegetation.

All critical soil surfaces require some type of cover to reduce erosion sediment yields. The most common kinds of soil covers are diagrammed in Figure 6, as presented by Foote et al.1/

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* The term "ecosystem" was first proposed by A. G. Tansley, a British ecologist, in 1935. It is defined as an energy-exchanging community of organisms and their ambient environment.

1/ Foote, L. E., D. L. Kill, and A. H. Bolland, "Erosion Prevention and Turf Establishment Manuals," Minnesota Department of Highways, p. 12 (1970).

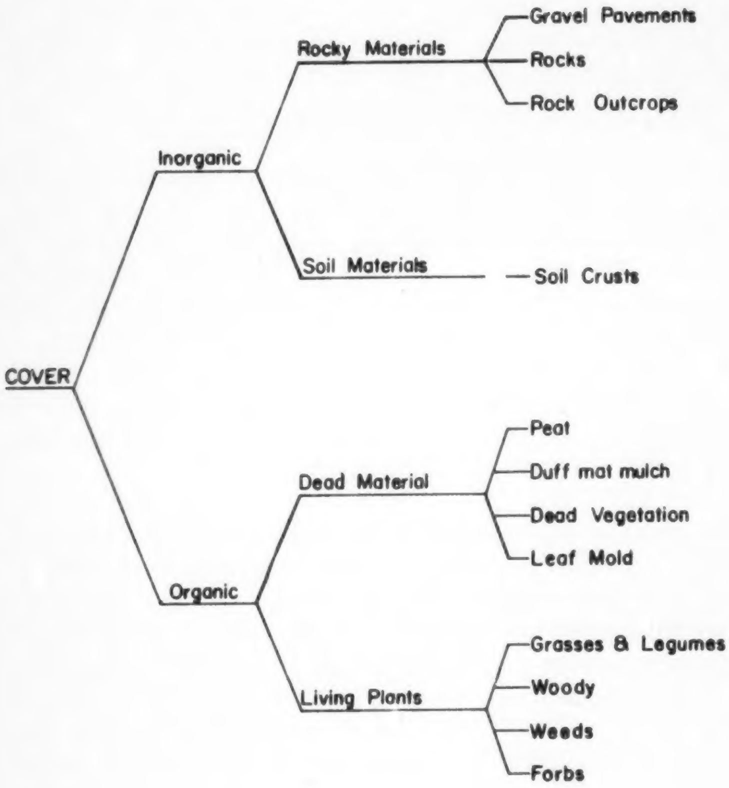

COVER
Inorganic
Rocky Materials
Gravel Pavements
Rocks
Rock Outcrops
Soil Materials
Soil Crusts
Organic
Dead Material
Peat
Duff mat mulch
Dead Vegetation
Leaf Mold
Living Plants
Grasses & Legumes
Woody
Weeds
Forbs

Figure 6 - Graph Shows Cover Classification of the Groups of Materials Which Can be Used to Protect the Disturbed Soils From Erosion

B. Plant Environments and Construction

Plants growing on steep road cuts, even in humid regions, are living in an ecological minidesert; whereas plants on fills in actual desert areas may have adequate soil water because of the effect of the waterproof road surface acting as a miniwatershed. Plants growing in some road ditches and in seepage areas are, in fact, in a marsh environment.

Cut slopes should be made as gentle as economically feasible to reduce sediment losses until plants can be established. In general, the following scientific guidelines and rules-of-thumb apply to water and soil erosion losses on cut slopes:

1. A doubling of the slope grade increases soil erosion losses by a factor of 2.5. Effective slope grade can be reduced by benching (Figure 7).

2. A doubling of the length of slope increases sediment losses by a factor of 1.5. Effective slope length can be reduced by diversion terraces.

3. Because of differences in soil texture, structure, and soil voids (porosity), rainfall will enter (infiltrate) some bare soils at least 10 times faster than it will others. On cut and fill slopes, soil texture may be made a better medium for plant growth by hauling in sands on impervious clays and by intermixing clays on existing sandy soils. Surface soil structure can be improved for growing plants on all kinds of mineral soils by incorporating organic matter.1/

To enhance the ecological environment on cut slopes for plant growth, infiltration of rainfall should be increased. The steady-state rate of infiltration into a cut slope can be increased by these conditions or practices:

1. Providing gentle slopes.

2. Placing a mulch layer on the surface.

3. Applying calcium to help aggregate a crumb structure in the soil.

1/ Donahue, R. L., "Our Soils and Their Management," Interstate Printers and Publishers, Danville, Illinois, 3rd ed., pp. 291-361 (1970).

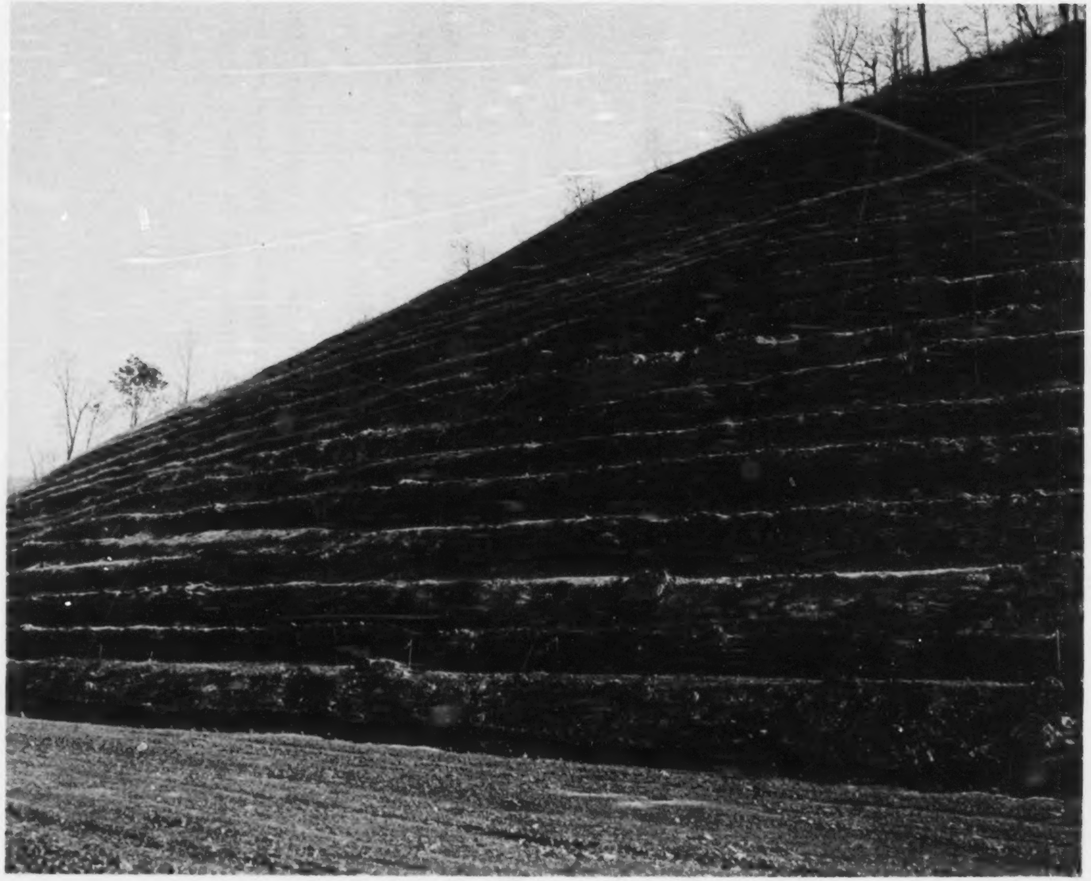


Figure 7 - Effective Slope Grade Can Be Reduced by Benching (stair-step grading), as Shown Here in West Virginia (Courtesy of Roy Blaser)

4. Establishing a permanent living vegetation over the surface.

5. Earthworms and other life in the soil.

Steady-state rates of infiltration can be decreased by these conditions.

1. Providing steep slopes;

2. Bare soils;

3. Shallow soils over an impervious layer or bedrock;

4. Swelling clays such as montmorillonite;

5. Fine-textured soils;

6. Dispersed soils such as sodium-saturated clays;

7. Compacted soils;

8. Cold and frozen soils;

9. Absence of life in the soils; and

10. Manipulation or working of wet clay soil by heavy machinery.

Because of extreme variations in ecological environments within close proximity to each other, road cuts, fills, and drainage ditches should be treated as separate sites when soils along a roadway are sampled. If the soil tests dictate three separate lime and fertilizer recommendations on the cut slopes, roadside drainage ways, and fill slopes, separate treatments should be given. Separate seeding mixtures may also be used; or, alternately, one seeding mixture with seeds of plant adapted for these three ecological conditions.

Soils disturbed by burying a pipeline, a powerline, or a telephone cable are likewise not uniform ecological environments for plant growth. A buried line across wetlands may reduce the natural surface and subsurface drainage across the slope, resulting in excess water on the upslope side of the construction line. Sometimes this damming effect will kill natural or planted vegetation. The environment on the disturbed soil directly over the trench may be more droughty or wetter than the original soil, depending on local topography and subsurface flow of water. Any mounded soil will be drier than before the construction activity. In addition, the physical condition of the soil has been altered, which results in either a more or a less favorable plant bed. The soil nutrient supplying power of the soil has also been altered; again, it may be more favorable or less favorable for plant growth. The variations in soil conditions over a buried line indicate the desirability of separate soil sampling for plant nutrient testing and call for a seeding mixture of species that do best in each ecological environment.

The same general variations in ecological environments following urban developments, shopping center construction, drainage ditch digging, and ski slope developments must be recognized. Soils should be sampled, treated with lime and fertilizer (if indicated by soil test), and their growing capacity considered separately when deciding on the seeding mixture.

To achieve adequate plant establishment, it may therefore be necessary to drain seepage areas, and to irrigate other seedings and plantings on road cut slopes, on mounded fills, and on sandy and droughty soils, even if rainfall is adequate for plant establishment on other minienvironments. There is no practical scientifically accurate way to determine when irrigation is needed on such variable sites; as a rule-of-thumb, when wilting starts to occur on the most droughty areas, it is time to irrigate.

C. Climate and Plant Growth

The climatic requirements of plant growth are confined to precipitation as a source of available water, and critical temperatures. On level upland sites, very few higher plants will grow with less than 25 cm (10 in.) of annual precipitation. In valleys where water accumulates, plants will grow even in arid climates.

Average annual precipitation in the United States is 76 cm (30 in.), approximately 25 cm (10 in.) of which runs off the surface of the soil into drainageways. Extremes are exemplified by Hawaii, with a variation of less than 51 cm (20 in.) to more than 762 cm (300 in.); and by California with a range of zero for most years to 409 cm (161 in.). Wide variations in means also occur in the State of Washington, with a range of 45 cm (18 in.) to 381 cm (150 in.).

There is a direct relationship among effective precipitation, natural vegetation, and sediment yield. In general the less the annual rainfall, the more intense it falls; and the less the rainfall, the more sparse the vegetation. Intense rainfall on sparse vegetation results in high sediment yield. These statements are documented by Langbeim and Schumm[1/] (Figure 8).

With 25 cm (10 in.) of precipitation, the vegetative type is desert shrub, and the annual sediment yield is 280 mt/km^2 (800 $tons/mile^2$). With 51 cm (20 in.) of annual precipitation, grasses are the dominant vegetation, and the annual sediment yield is 210 mt/km^2 (600 $tons/mile^2$).

Forests are dominant when 102 cm (40 in.) or more of precipitation are received, and the sediment yield is 105 mt/km^2 (300 $tons/mile^2$). In summary, intense rainfall on soils with sparse vegetation results in high sediment yields.

The emphasis of this manual is on the science and art of quickly and successfully establishing plants for ground cover to reduce sediment pollution to water resulting from soil erosion associated with construction activities.

Normal growing temperatures for most plants is from 10°C (50°F) to 32°C (90°F). Critical temperatures for the growth of most higher plants vary from below -46°C (-50°F) to 49°C (120°F). Optimum temperature for temperate grasses is about 20°C (68°F) and for tropical grasses about 35°C (95°F).

Each plant has an available soil moisture adaptation and an air temperature tolerance. The tolerance to low temperatures has been used as a basis for the development of a map of the 48 States and of southern Canada entitled "Zones of Plant Hardiness" (Figure 9). This map is divided into 10 zones, each with a range in minimum temperatures from below -46°C (-50°F) to -1°C (30°F) to 4°C (40°F). In addition, a list of common persistent plants is given for each of the 10 plant hardiness zones, listed by scientific and common name. Many of these native plants are used for planting to control sediment.

An independent attempt has been made to develop a more detailed plant growth map for the United States. It considers more factors of plant growth than just tolerance to minimum temperature (Figure 10).

[1/] Langbeim, W. B., and C. A. Schumm, "Yield of Sediment in Relation to Mean Annual Precipitation," American Geophysical Union Transactions, 39:1076-1084 (1958).

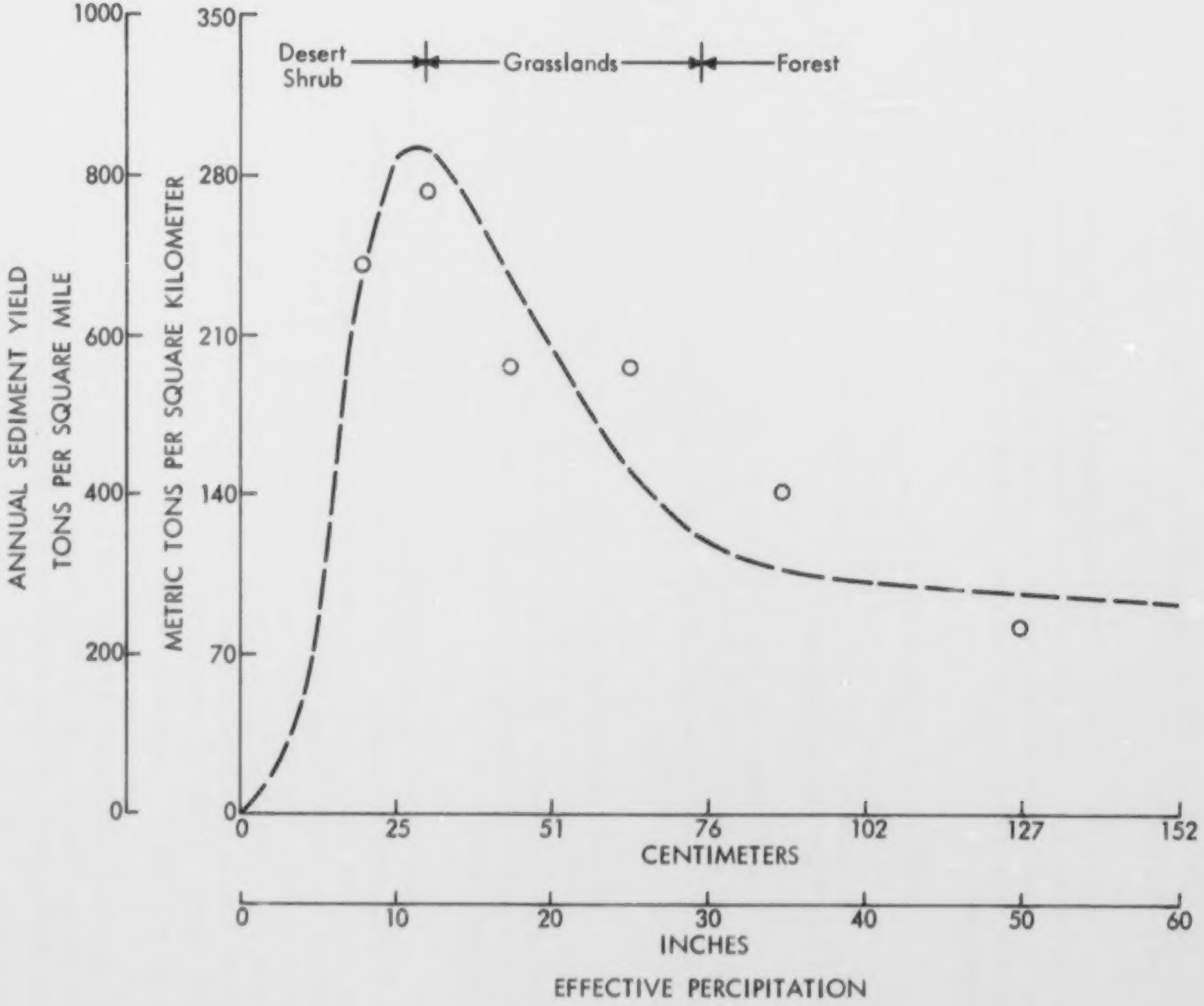
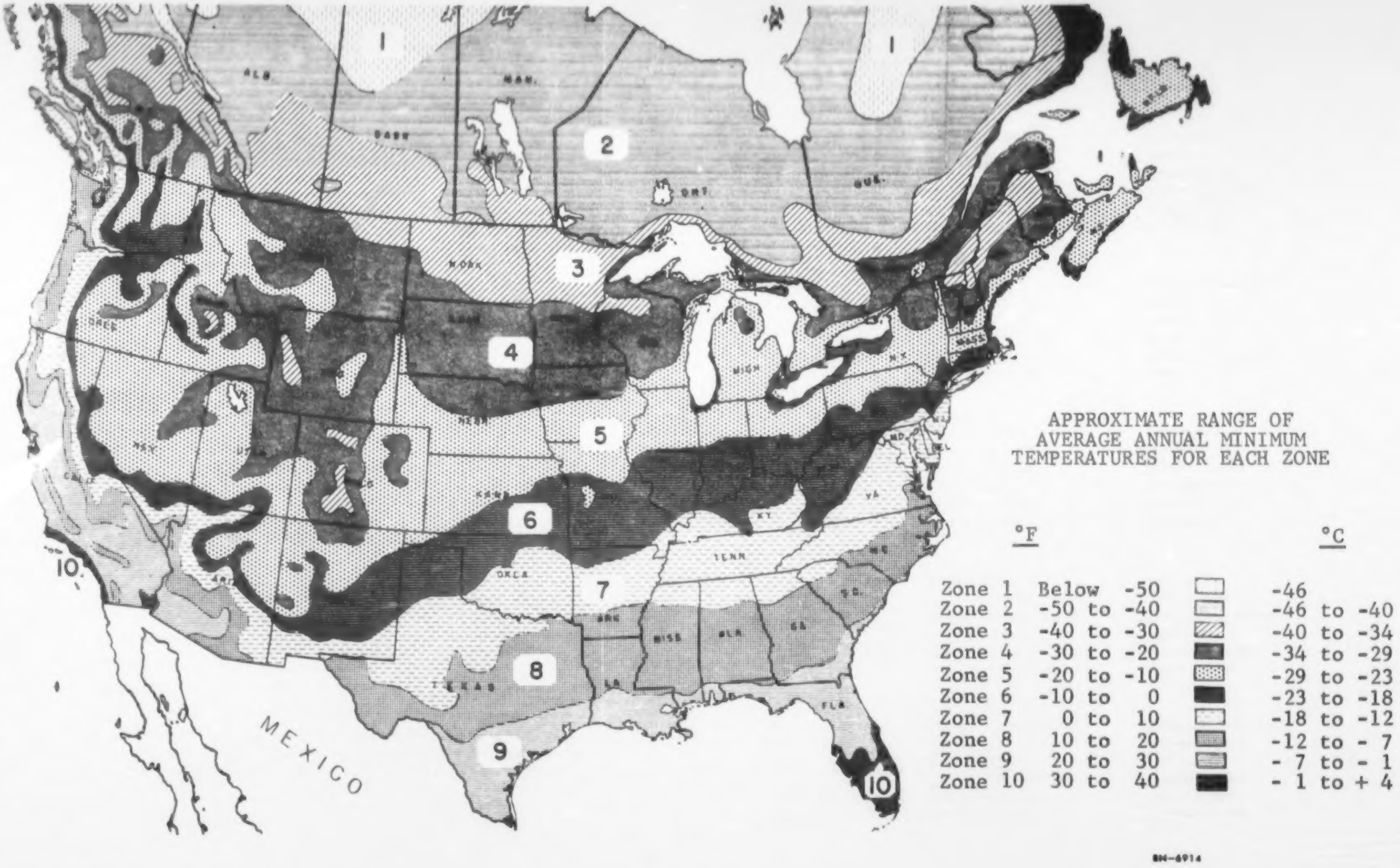


Figure 8 - General Relationships Among Effective Precipitation, Vegetation, and Sediment Yield


1
2
3
4
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7
8
9
10
MEXICO
APPROXIMATE RANGE OF
AVERAGE ANNUAL MINIMUM
TEMPERATURES FOR EACH ZONE
°F
°C
Zone 1 Below -50 -46
Zone 2 -50 to -40 -46 to -40
Zone 3 -40 to -30 -40 to -34
Zone 4 -30 to -20 -34 to -29
Zone 5 -20 to -10 -29 to -23
Zone 6 -10 to 0 -23 to -18
Zone 7 0 to 10 -18 to -12
Zone 8 10 to 20 -12 to - 7
Zone 9 20 to 30 - 7 to - 1
Zone 10 30 to 40 - 1 to + 4
BN-6914

Figure 9 - The Zones of Plant Hardiness--Numbers 1 Through 10 Reference the Temperature-Plant Relationships, Examples of Which are Found on the Next Page (Agricultural Research Service, Miscellaneous Publication 814, U.S. Department of Agriculture, 1965)

Following are names of representative persistent plants listed under the coldest zones in which they will normally succeed. Such plants may serve as useful indicators of the cultural possibilities of each zone.

	Botanical Name	Common Name
ZONE 1 -46°C (below -50°F)	*Betula glandulosa*	Dwarf birch
	Empetrum nigrum	Crowberry
	Populus tremuloides	Quaking aspen
	Potentilla pensylvanica	Pennsylvania cinquefoil
	Rhododendron lapponicum	Lapland rhododendron
	Salix reticulata	Netleaf willow
ZONE 2 -46 to -40°C (-50 to -40°F)	*Betula papyrifera*	Paper birch
	Cornus canadensis	Bunchberry dogwood
	Elaeagnus commutata	Silverberry
	Larix laricina	Eastern larch
	Potentilla fruticosa	Bush cinquefoil
	Viburnum trilobum	American cranberry bush
ZONE 3 -40 to -34°C (-40 to -30°F)	*Berberis thunbergi*	Japanese barberry
	Elaeagnus angustifolia	Russian olive
	Juniperus communis	Common juniper
	Lonicera tatarica	Tatarian honeysuckle
	Malus baccata	Siberian crabapple
	Thuja occidentalis	American arborvitae
ZONE 4 -34 to -29°C (-30 to -20°F)	*Acer saccharum*	Sugar maple
	Hydrangea paniculata	Panicle hydrangea
	Juniperus chinensis	Chinese juniper
	Ligustrum amurense	Amur River privet
	Parthenocissus quinquefolia	Virginia creeper
	Spiraea vanhouttei	Vanhoutte spirea
ZONE 5 -29 to -23°C (-20 to -10°F)	*Cornus florida*	Flowering dogwood
	Deutzia gracilis	Slender deutzia
	Ligustrum vulgare	Common privet
	Parthenocissus tricuspidata	Boston ivy
	Rosa multiflora	Japanese rose
	Taxus cuspidata	Japanese yew
ZONE 6 -23 to -18°C (-10 to 0°F)	*Acer palmatum*	Japanese maple
	Buxus sempervirens	Common box
	Euonymus fortunei	Winter creeper
	Hedera helix	English Ivy
	Ilex opaca	American holly
	Ligustrum ovalifolium	California privet
ZONE 7 -18 to -12°C (0 to 10°F)	*Acer macrophyllum*	Bigleaf maple
	Azalea Kurume hybrids	Kurume azaleas
	Cedrus atlantica	Atlas cedar
	Cotoneaster microphylla	Small-leaf cotoneaster
	Ilex aquifolium	English holly
	Taxus baccata	English yew
ZONE 8 -12 to -7°C (10 to 20°F)	*Arbutus unedo*	Strawberry tree
	Choisya ternata	Mexican orange
	Olearia haastii	New Zealand daisy-bush
	Pittosporum tobira	Japanese pittosporum
	Prunus laurocerasus	Cherry-laurel
	Viburnum tinus	Laurestinus
ZONE 9 -7 to -1°C (20 to 30°F)	*Asparagus plumosus*	Asparagus fern
	Eucalyptus globulus	Tasmanian blue gum
	Eugenia paniculata	Brush cherry
	Fuchsia hybrids	Fuchsia
	Grevillea robusta	Silk-oak
	Schinus molle	California pepper tree
ZONE 10 -1 to +4°C (30 to 40°F)	*Bougainvillea spectabilis*	Bougainvillea
	Cassia fistula	Golden shower
	Eucalyptus citriodora	Lemon eucalyptus
	Ficus elastica	Rubber plant
	Musa ensete	Banana
	Roystonea regia	Royal palm

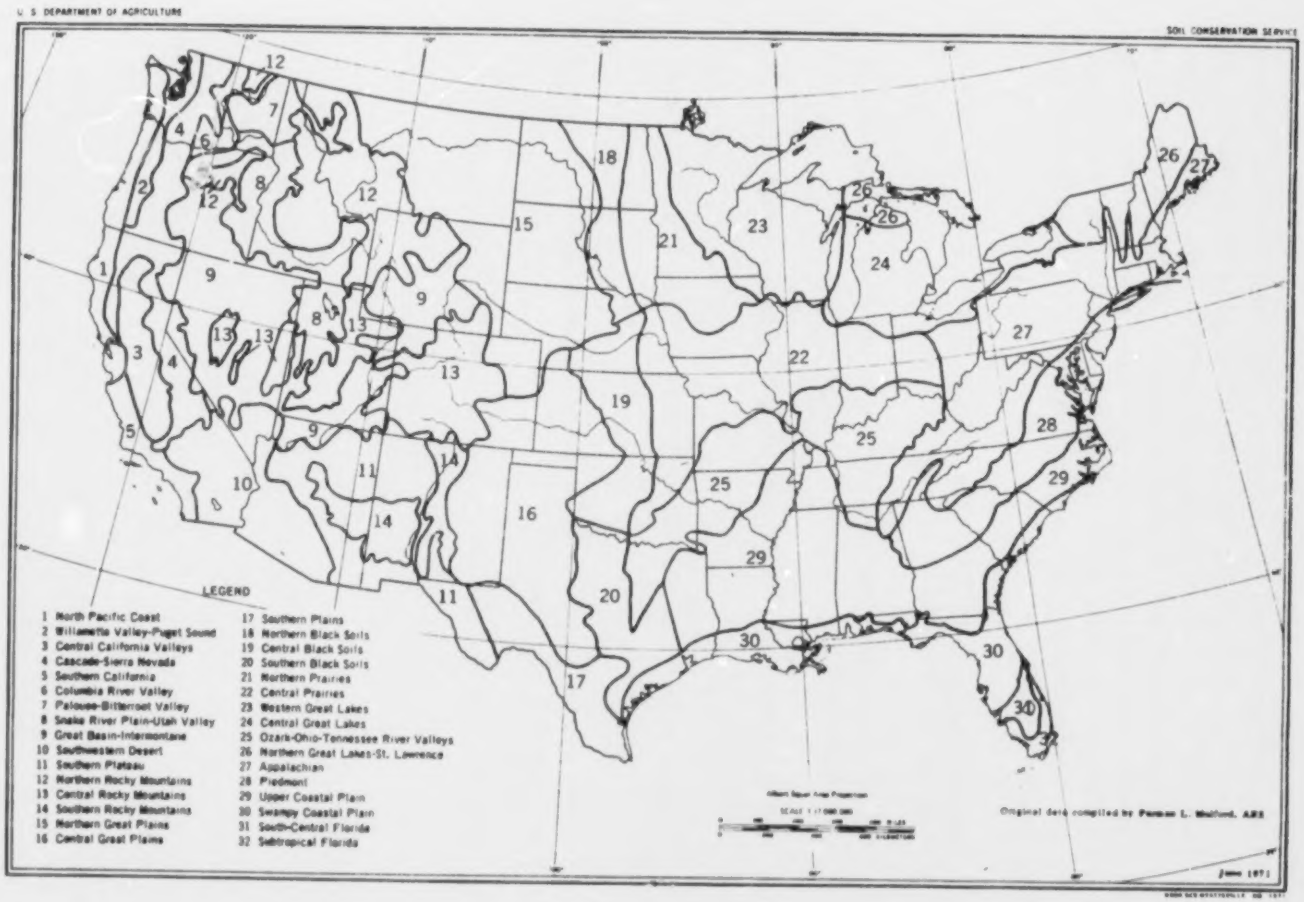
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
LEGEND
1 North Pacific Coast
2 Willamette Valley-Puget Sound
3 Central California Valleys
4 Cascade-Sierra Nevada
5 Southern California
6 Columbia River Valley
7 Palouse-Bitterroot Valley
8 Snake River Plain-Utah Valley
9 Great Basin-Intermontane
10 Southwestern Desert
11 Southern Plateau
12 Northern Rocky Mountains
13 Central Rocky Mountains
14 Southern Rocky Mountains
15 Northern Great Plains
16 Central Great Plains
17 Southern Plains
18 Northern Black Soils
19 Central Black Soils
20 Southern Black Soils
21 Northern Prairies
22 Central Prairies
23 Western Great Lakes
24 Central Great Lakes
25 Ozark-Ohio-Tennessee River Valleys
26 Northern Great Lakes-St. Lawrence
27 Appalachian
28 Piedmont
29 Upper Coastal Plain
30 Swampy Coastal Plain
31 South-Central Florida
32 Subtropical Florida
Original data compiled by Perman L. Mulford, ARS

Figure 10 - Plant Growth Regions of the United States. "Adventures with Native Plants that Passed Their Tests," In: "Landscape for Living," The Yearbook of Agriculture, U.S. Department of Agriculture, pp. 176-184 (1972). Map updated by William R. van Dersal for The 1972 Yearbook of Agriculture.

All important ecological factors of plant-soil-climate relationships were utilized in delineating the 32 regions. Then the various regions were tested by removing wild plants or collecting wild seeds and planting them in other parts of a given region to test the validity of the boundaries. If a species of plant was not adapted to the entire region, or if it was adapted to a more extensive adjoining area, the boundaries on the map were redrawn. Based upon actual experimentation with native plants within and among regions on comparable soils, the following conclusions were drawn:

1. Within any one region, the native plants would be adapted if dug and transplanted on similar soils.

2. Plants from Regions 12 and 13 are usually adapted in Regions 24, 25, 27, and 28. The reverse is seldom true.

3. Plants from Regions 27 and 28 are usually adapted to Regions 1, 2, 24, 25, and 29.

4. Plants moved from Regions 1, 2, and 4 will usually grow well in Regions 29 and 30.

5. Plants from Region 5 will almost always grow successfully in Regions 31 and 32 and vice versa.

6. Plants from Region 20 will grow and reproduce well in Region 29.[1]

D. Soil Productivity

The civil engineer considers soil to be a natural aggregate of mineral grains, with or without organic matter, that can be separated by gentle mechanical means such as agitation in water. (This definition of soil is used in the manual.) By contrast, rock is a natural aggregate of mineral grains bound by strong and permanent cohesive forces.[2]

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[1] van Dersal, R., "Adventures with Native Plants that Passed their Tests," in "Landscape for Living," the Yearbook of Agriculture, U.S. Department of Agriculture, pp. 176-184 (1972), and van Dersal, R., "Native Woody Plants of the United States," U.S. Department of Agriculture, Miscellaneous Publication 303 (1938).

[2] Peck, R. B., W. E. Hanson, and T. H. Thornburn, Foundation Engineering, John Wiley and Sons, Inc., 2nd ed., 514 pages, p. 3, New York (1974).

The terms soil and regolith often have the same meaning to a geologist and are equivalent to all unconsolidated material that rests on bedrock. Thus, the word "soil" to a geologist may apply to all materials on the surface of the earth overlying bedrock, including weathered bedrock (soil parent materials), windblown sand, loessial silt, glacial materials, alluvium, volcanic ash, and accumulations of peat and muck materials.1/

In agriculture, the surface of the earth in which plant roots are growing is usually designated as soil, and the underlying substratum as geologic material or parent material. Soil is also considered as the surface 2 m, or the depth to bedrock or other layers that restrict root extension.

No generalization can be made about soil and underlying parent materials that have been intermixed by construction activities. Vertically and horizontally, every few feet the nature of the material may change; however, it changes within predictable limits. The limits and boundaries of predictable change and predictable commonalities of characteristics of soil and underlying parent materials is the essence of the new system of soil classification and the science of surface geology.

Within the meaning of the ecological sciences including all soil and plant relationships, soil includes the weathered surface to depths of about 2 m (6 ft). Since many road cuts and other construction activities disturb soils and parent materials below 2 m (6 ft), the composition of materials on slopes is variable. To predict the nature of their materials and probable treatments necessary for successful establishment of vegetation requires a knowledge of both the soil and the underlying parent material. A body of new soil knowledge is available in the system of soil taxonomy established by the Soil Conservation Service in cooperation with the land-grant universities. A knowledge of the corresponding underlying parent materials is less predictable because less is known about them.

Soils have been classified and mapped since 1899, but only from 1965 has the system carried in the name an interpretive connotation of relative productivity for vegetation.

The relative productivity of soils can be inferred by reference to the soil classification system now in use by the Soil Conservation Service.2/

1/ American Geological Institute, Glossary of Geology and Related Sciences, National Academy of Sciences--National Research Council, Washington, D.C., 2nd ed., 197 pages, pp. 242 and 272 (1960).

2/ Soil Conservation Service, "Soil Taxonomy," Soil Survey Staff, U.S. Department of Agriculture (in press, 1975).

The Soil Great Groups which were selected for nine of the 10 documented demonstration sites in Section IV have coined names with roots that are indicative of low productivity, as follows:

Cry - cold

Dystr - few plant nutrients

Frag - compacted horizon

Hapl - simple, least advanced horizon

Id - dry

Pale - old and highly weathered

Ult - ultimate in weathering

Xer - dry

In addition to the use of Soil Great Groups as an indicator of soils of low productivity for plants, one of the case studies or demonstration sites was selected because the exposed geologic material on a deep cut slope contained large amounts of pyrite which, upon weathering, produced very strongly acidic conditions that killed the established bermuda grass. Collectively, these 10 selected demonstration areas represent about 38.54% of the land area of the United States (Table 1).

Because the surface of the earth disturbed by construction activities often extends below the first 2 m, the following two maps of the United States are considered extremely useful:

1. General Soil Map of the United States on which the 10 demonstration sites are located (Figure 11), which portrays the 10 soil orders and the 47 suborders in the new U.S. system of soil taxonomy. This map delineates the soils within the two highest categories of classification.[1] The lower categories in the system include 185 Great Groups, 970 subgroups, 4,500 families, and about 11,000 series so far recognized.

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[1] Soil Conservation Service, "Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys," Soil Survey Staff, U.S. Department of Agriculture, Washington, D.C. (an interim publication for inservice use), October 1973.

TABLE 1

SUMMARY OF EXTENT OF SOIL GREAT GROUPS IN THE 10 DEMONSTRATION AREAS OF SECTION IV

Great Groups/Formation	km^2	$Miles^2$	% of U.S.
1. California			
Cryumbrepts	19,810	7,650	0.22
2. Idaho			
Xeropsamments	8,318	3,250	0.10
Xerorthents	296,835	115,110	3.22
3. New Mexico			
Haplargids	685,300	264,600	7.48
4. Colorado			
Cryorthents	26,000	10,000	0.28[a]
5. Texas			
Weches Formation	91,710	about 35,410	about 1.00
6. Mississippi			
Paleudults	465,550	179,750	5.08
Fragiudalfs	100,080	38,640	1.09
7. West Virginia			
Dystrochrepts	223,260	86,200	2.44
Hapludults		(See Virginia)	
8. Virginia			
Hapludults	412,120	159,120	4.50
9. Massachusetts			
Haplorthods	297,020	114,680	3.24
10. Alaska			
Cryaquepts	905,204	349,500	9.89
Total	3,531,207	1,363,910	38.54

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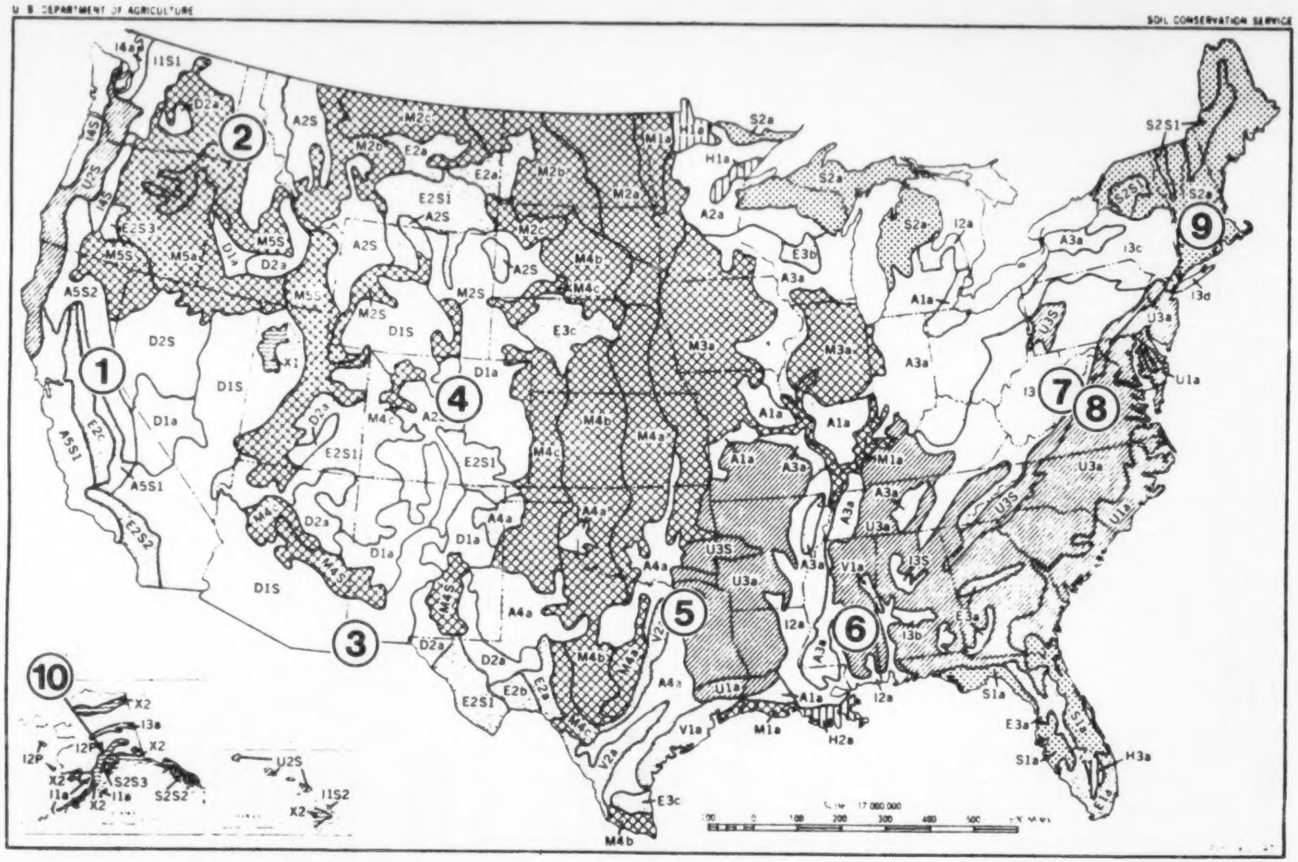
[a] Estimated by John E. McClelland, Director, Soil Survey Operations, Soil Conservation Service.


U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
1
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3
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5
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7
8
9
10
I4a
I1S1
D2a
A2S
M2c
M2b
E2a
M2b
M1a
H1a
S2a
S2a
A2a
S2a
I2a
S2S1
E2S1
A2S
M2c
M2a
E3b
A3a
I3c
S2a
E2S3
M5S
M5a
D1a
M5S
D2a
A2S
M4b
M4c
A3a
A1a
U3S
I3d
U3a
A5S2
D2S
M2S
D1S
M2S
E3c
M3a
M3a
A3a
D1S
X1
D1a
M4c
A2
D1a
M4b
M4a
A1a
A1a
I3
U1a
A5S1
D1a
E2c
D2a
E2S1
E2S1
M4c
A1a
A3a
M1a
U3a
A5S1
E2S2
M4a
D2a
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A3a
U3S
U1a
M4a
D1a
U3S
A3a
V1a
I3S
D1S
M4S
A4a
U3a
E3a
D2a
D2a
E2S1
E2b
E2a
M4b
M4a
A4a
V2a
I2a
A3a
I3b
U1a
A1a
M1a
H2a
I2a
S1a
E3a
S1a
H3a
E1a
V1a
V2a
E3c
M4b
X2
I3a
I2P
X2
I2P
X2
S2S3
I1a
I1a
X2
S2S2
U2S
I1S2
X2
Scale 1:17,000,000
100
0
100
200
300
400
500

Figure 11 - General Soil Map of the United States Showing the 10 Soil Orders and 47 Soil Suborders. The numbers refer to the demonstration sites, as follows: 1. California; 2. Idaho; 3. New Mexico; 4. Colorado; 5. Texas; 6. Mississippi; 7. West Virginia; 8. Virginia; 9. Massachusetts; and 10. Alaska. Number 11 is not a specific location. (See legend on next page.)

LEGEND FOR "GENERAL SOIL MAP OF THE UNITED STATES"
(SOIL ORDERS AND SUBORDERS)

ALFISOLS

AQUALFS
A1a Aqualfs with Udalfs, Haplaquepts, Udolls; gently sloping.

BORALFS
A2a Boralfs with Udipsamments and Histosols; gently and moderately sloping.
A2S Cryoboralfs with Borolls, Cryochrepts, Cryorthods, and Rock outcrops; steep.

UDALFS
A3a Udalfs with Aqualfs, Aquolls, Rendolls, Udolls, and Udults; gently or moderately sloping.

USTALFS
A4a Ustalfs with Ustochrepts, Ustolls, Usterts, Ustipsamments, and Ustorthents; gently or moderately sloping.

XERALFS
A5S1 Xeralfs with Xerolls, Xerorthents, and Xererts; moderately sloping to steep.
A5S2 Ultic and lithic subgroups of Haploxeralfs with Andepts, Xerults, Xerolls, and Xerochrepts; steep.
E2S2 Xerorthents with Xeralfs and Xerolls; steep.
E2S3 Cryorthents with Cryopsamments and Cryandepts; gently sloping to steep.

PSAMMENTS
E3a Quartzipsamments with Aquults and Udults; gently or moderately sloping.
E3b Udipsamments with Aquolls and Udalfs; gently or moderately sloping.
E3c Ustipsamments with Ustalfs and Aquolls; gently or moderately sloping.

ARIDISOLS

ARGIDS
D1a Argids with Orthids, Orthents, Psamments, and Ustolls; gently and moderately sloping.
D1S Argids with Orthids, gently sloping; and Torriothents, gently sloping to steep.

ORTHIDS
D2a Orthids with Argids, Orthents, and Xerolls; gently or moderately sloping.
D2S Orthids, gently sloping to steep, with Argids, gently sloping; lithic subgroups of Torriorthents and Xerorthents, both steep.

ENTISOLS

AQUENTS
E1a Aquents with Quartzipsamments, Aquepts, Aquolls, and Aquods; gently sloping.

ORTHENTS
E2a Torriorthents, steep, with borollic subgroups of Aridisols; Usterts and aridic and vertic subgroups of Borolls; gently or moderately sloping.
E2b Torriorthents with Torrerts; gently or moderately sloping.
E2c Xerorthents with Xeralfs, Orthids, and Argids; gently sloping.
E2S1 Torriorthents; steep, and Argids, Torrifluvents, Ustolls, and Borolls; gently sloping.

HISTOSOLS

HISTOSOLS
H1a Hemists with Psammaquents and Udipsamments; gently sloping.
H2a Hemists and Saprists with Fluvaquents and Haplaquepts; gently sloping.
H3a Fibrists, Hemists, and Saprists with Psammaquents; gently sloping.

INCEPTISOLS

ANDEPTS
I1a Cryandepts with Cryaquepts, Histosols, and Rock land; gently or moderately sloping.
I1S1 Cryandepts with Cryochrepts, Cryumbrepts, and Cryorthods; steep.
I1S2 Andepts with Tropepts, Ustolls, and Tropofolists; moderately sloping to steep.

AQUEPTS
I2a Haplaquepts with Aqualfs, Aquolls, Udalfs, and Fluvaquents; gently sloping.
I2P Cryaquepts with cryic great groups of Orthents, Histosols, and Ochrepts; gently sloping to steep.

OCHREPTS
I3a Cryochrepts with cryic great groups of Aquepts, Histosols, and Orthods; gently or moderately sloping.
I3b Eutrochrepts with Uderts, gently sloping.
I3c Fragiochrepts with Fragiaquepts, gently or moderately sloping; and Dystrochrepts, steep.
I3d Dystrochrepts with Udipsamments and Haplorthods; gently sloping.
I3S Dystrochrepts, steep, with Udalfs and Udults; gently or moderately sloping.

UMBREPTS
I4a Haplumbrepts with Aquepts and Orthods; gently or moderately sloping.
I4S Haplumbrepts and Orthods; steep, with Xerolls and Andepts; gently sloping.

MOLLISOLS

AQUOLLS
M1a Aquolls with Udalfs, Fluvents, Udipsamments, Ustipsamments, Aquepts, Eutrochrepts, and Borolls; gently sloping.

BOROLLS
M2a Udic subgroups of Borolls with Aquolls and Ustorthents; gently sloping.
M2b Typic subgroups of Borolls with Ustipsamments, Ustorthents, and Boralfs; gently sloping.
M2c Aridic subgroups of Borolls with Borollic subgroups of Argids and Orthids, and Torriorthents; gently sloping.
M2S Borolls with Boralfs, Argids, Torriorthents, and Ustolls; moderately sloping or steep.

UDOLLS
M3a Udolls, with Aquolls, Udalfs, Aqualfs, Fluvents, Psamments, Ustorthents, Aquepts, and Albolls; gently or moderately sloping.

USTOLLS
M4a Udic subgroups of Ustolls with Orthents, Ustochrepts, Usterts, Aquents, Fluvents, and Udolls; gently or moderately sloping.
M4b Typic subgroups of Ustolls with Ustalfs, Ustipsamments, Ustorthents, Ustochrepts, Aquolls, and Usterts. Gently or moderately sloping.
M4c Aridic subgroups of Ustolls with Ustalfs, Orthids, Ustipsamments, Ustorthents, Ustochrepts, Torriorthents, Borolls, Ustolls, and Usterts, gently or moderately sloping.
M4S Ustolls with Argids and Torriorthents; moderately sloping or steep.

XEROLLS
M5a Xerolls with Argids, Orthids, Fluvents, Cryoboralfs, Cryoborolls, and Xerorthents; gently or moderately sloping.
M5S Xerolls with Cryoboralfs, Xeralfs, Xerorthents, and Xererts; moderately sloping or steep.

SPODOSOLS

AQUODS
S1a Aquods with Psammaquents, Aquolls, Humods, and Aquults, gently sloping.

ORTHODS
S2a Orthods with Boralfs, Aquents, Orthents, Psamments, Histosols, Aquepts, Fragiochrepts, and Dystrochrepts; gently or moderately sloping.
S2S1 Orthods with Histosols, Aquents, and Aquepts; moderately sloping or steep.
S2S2 Cryorthods with Histosols; moderately sloping or steep.
S2S3 Cryorthods with Histosols, Andepts and Aquepts; gently sloping to steep.

ULTISOLS

AQUULTS
U1a Aquults with Aquents, Histosols, Quartzipsamments, and Udults; gently sloping.

HUMULTS
U2S Humults with Andepts, Tropepts, Xerolls, Ustolls, Orthox, Torrox, and Rock land; gently sloping to steep.

UDULTS
U3a Udults with Udalfs, Fluvents, Aquents, Quartzipsamments, Aquepts, Dystrochrepts, and Aquults; gently or moderately sloping.
U3S Udults with dystrochrepts; moderately sloping or steep.

VERTISOLS

UDERTS
V1a Uderts with Aqualfs, Eutrochrepts, Aquolls, and Ustolls; gently sloping.

USTERTS
V2a Usterts with Aqualfs, Orthids, Udifluvents, Aquolls, Ustolls, and Torrerts; gently sloping.

Areas with little soil

X1 Salt flats.
X2 Rock land (plus permanent snow fields and glaciers).

Slope classes

Gently sloping—Slopes mainly less than 10 percent, including nearly level.
Moderately sloping—slopes mainly between 10 and 25 percent.
Steep—Slopes mainly steeper than 25 percent.

Reproduced from
best available copy.

2. Parent Materials Map of the United States (Figure 12).[1] This map gives the kinds of geologic parent materials that occur under the surface 2 m of soil.

E. Soil Surveys and Their Use for Construction Activities

Soil surveys have been made since 1899 by several agencies of our National Government. Beginning in 1935, soil surveys were started for the primary purpose of helping farmers reduce erosion losses. By mutual agreement, in November of 1952, these Government agencies were consolidated under the Soil Conservation Service, a branch of the United States Department of Agriculture, and designated the National Cooperative Soil Survey. The agricultural experiment station, an integral segment of each State agricultural university, is also a cooperating partner in the National Cooperative Soil Survey. Other cooperating agencies are the Forest Service and the Bureau of Land Management.

As of June 20, 1974, a total of about 508 million hectares (1.26 billion acres) have been surveyed out of a total land area of 919 million hectares (2.26 billion acres) in the United States. Detailed surveys have been completed for 340 million hectares (839 million acres). Reconnaissance surveys have been completed for 25 million hectares (62 million acres). Exploratory surveys in Alaska of 143 million hectares (354 million acres) have been completed.

In the National forests about 10 million hectares (24 million acres) of soils have been mapped in detail; and about 25 million hectares (65 million acres) have been mapped in a broader (reconnaissance) basis. The 36 million hectares (89 million acres) represents approximately half of the land are of the National forests.

Field mapping of soils for detailed surveys is usually done on a photographic mosaic at a scale of approximately 1:16,000 (4 in. to the mile or smaller). Soil maps are published on a photographic base at a scale of 1:20,000 (3.17 in. to the mile or smaller). The soil maps are published as a part of a standard soil survey report with a county as the usual basis. The mapping unit on most of the detailed soil maps is a phase of a soil series; before 1965 the mapping unit was designated as a phase of a soil type.

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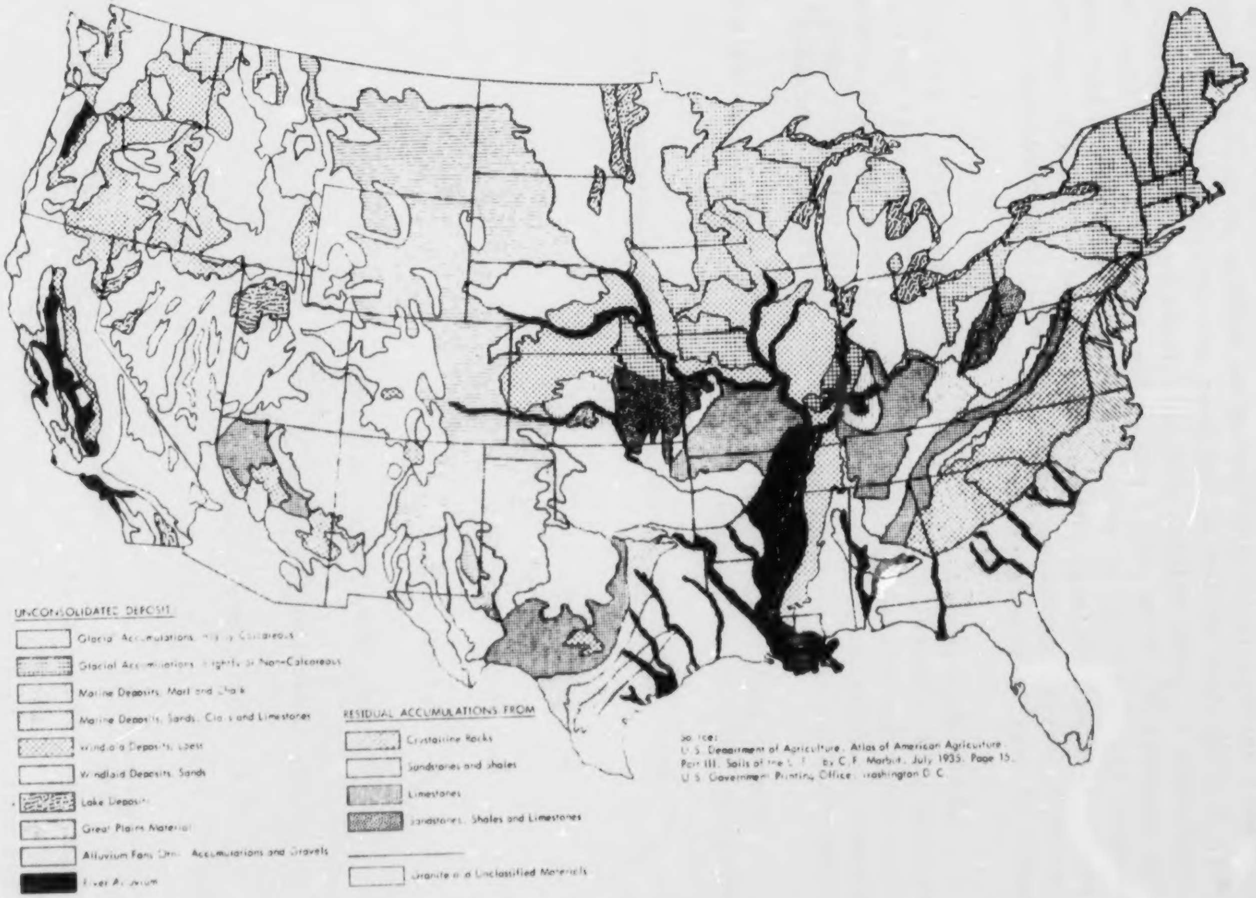
[1] Redrawn from: Marbut, C. F., "Parent Materials in Soils," In Atlas of American Agriculture, Part 3, Soils of the United States, U.S. Department of Agriculture (1935).


UNCONSOLIDATED DEPOSIT
Glacial Accumulations, Highly Calcareous
Glacial Accumulations, Slightly or Non-Calcareous
Marine Deposits, Marl and Chalk
Marine Deposits, Sands, Clays and Limestones
Windlaid Deposits, Loess
Windlaid Deposits, Sands
Lake Deposits
Great Plains Material
Alluvium Fans [illegible] Accumulations and Gravels
River Alluvium
RESIDUAL ACCUMULATIONS FROM
Crystalline Rocks
Sandstones and Shales
Limestones
Sandstones, Shales and Limestones
Granite and Unclassified Materials

Source:
U. S. Department of Agriculture, Atlas of American Agriculture, Part III, Soils of the U. S. by C. F. Marbut, July 1935, Page 15, U. S. Government Printing Office, Washington D. C.

Figure 12 - Parent Materials Map of the United States

A phase of a soil series, the most common unit of mapping in a detailed soil survey, is an engineering as well as an ecological entity. From data for the soil series an engineer may obtain information on subbase requirements, grade height, drainage requirements, and shrinkage-swelling criteria.[1] From soil series data a pedologist may predict the constant (K) factor in an erosion-predicting equation, plant species adaptation, internal drainage characteristics, water-holding capacity, water-release curves, approximate lime and fertilizer requirements, and the hazard of loss of plants by frost heaving.

In all soil survey reports published after 1965, a set of tables compares the USDA textural class for each horizon of the soil series mapping units with the unified system soil classification and the system of the American Association of State Highway Officials (AASHO). Table 2 is an example obtained from a recent soil survey report from Georgia.[2]

In each soil survey report issued after 1965 are tables with the following captions and content:

1. Soils and their estimated properties significant in engineering.

    a. Classification (see Table 2);

    b. Sieve analysis;

    c. Permeability;

    d. Available water capacity;

    e. Reaction (pH); and

    f. Shrink-swell potential.

1/ Michigan Department of State Highways, Field Manual of Soil Engineering, No. 1583, 5th ed., 474 pages, January 1970.

2/ Soil Survey of Dawson, Lumkin, and White Counties, Georgia, U.S. Department of Agriculture, Soil Conservation Service and Forest Service, in cooperation with the University of Georgia, College of Agriculture, Agricultural Experiment Station, p. 70, April 1972.

TABLE 2

A COMPARISON OF THE USDA TEXTURAL CLASS, THE UNIFIED SYSTEM, AND THE AASHO SYSTEM WITH HORIZONS OF APPLING SERIES

Soil Series Phase	Depth From Surface		Textural Class		
	cm	in.	USDA System	Unified System	AASHO System
Appling	0-18	0-7	Sandy Loam	SM	A-2
	18-132	7-52	Clay Loam	MH, MH-CH, CL, ML	A6, A7
	132-188	52-74	Sandy Loam	SM	A-4

2. Engineering interpretations.

a. Suitability as source of topsoil or road fill.

b. Soil features adversely affecting highway location, farm ponds, agricultural drainage, irrigation, terraces and diversions, waterways, foundations, and trafficways.

F. Engineering Erosion Control Criteria

To successfully establish vegetation on any soil, it is essential that the slopes be mechanically stable, the area be protected from runoff water, and surface erosion be temporarily minimized with a mulch. On long slopes it may be necessary to reduce effective slope length with a system of diversion or bench terraces.

Temporary erosion control is fundamentally important and a prerequisite to creating conditions favorable for plant growth. Therefore, basic considerations for construction design and planning are included here to emphasize this fact. An in-depth treatise on engineering erosion control methods, however, is beyond the scope of this manual. Detailed information is available in the several referenced documents.

Erosion control criteria should have these objectives:

1. Temporary control of sediment until more permanent structures and/or vegetation are established.

2. Detention of storm waters on the construction site and the release of these waters at nonerosive velocities.

3. Use of diversion terraces to divert water from the construction site.

4. Use of a serrated, stair-step, or bench design of cut slopes whenever feasible.1,2/

1/ Richards, D., and D. Ham, "Serrated Soft-Rock Cut Slopes," Department of Transportation, Federal Highway Administration, Washington, D.C., Report FHWA-RDDP-5-1, 30 pages, June 1973.

2/ International Engineering Company, Colorado Division of Highways, Project 170-2 (38), Vail Pass, June 1973.

5. Establishment of cut and fill slopes as flat as feasible consistent with the strengths of soils involved and economics. Slope stability depends on length and steepness, soil strength, moisture content, density, and other factors.[1]

Temporary erosion and sediment control measures may include installation of the following:[2]

a. Sedimentation traps or basins;

b. Berms;

c. Slope drains;

d. Toe-slope ditches;

e. Diversion channels; and

f. Haul roads.

Summary of these six measures and other engineered erosion control criteria have been developed by the Highway Research Board[3] and are summarized in tabular form in three columns entitled "Treatment Practice," "Advantages," and "Problems," in Table 3.

G. Physical Plant Bed Parameters

The ideal physical plant bed must provide mechanical support for plant roots, plus water and air. Each day in the life of the plant the soil must be in such physical condition as to permit roots to elongate, as well as to exchange gases and absorb water and essential elements. With too much water in the plant bed, carbon dioxide gas increases to toxic levels because of a deficiency of oxygen for root respiration.

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[1] Little, A. L., "Foundations," Edward Arnold, Ltd., London, p. 3 (1961).

[2] Federal Highway Administration, "Suggestions for Temporary Erosion and Siltation Control Measures," U.S. Department of Transportation, 40 pages, February 1973.

[3] Highway Research Board, "National Cooperative Highway Research Program Synthesis of Highway Practice, No. 18, Erosion Control on Highway Construction," Division of Engineering, National Research Council, National Academy of Sciences--National Academy of Engineering, pp. 42-46 (1973).

TABLE 3

ENGINEERING EROSION CONTROL CRITERIA[a/]

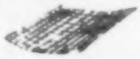
Treatment Practice	Advantages	Problems
ROADWAY DITCHES		
Check Dams 	Maintain low velocities Catch sediment Can be constructed of logs, shot rock, lumber, masonry or concrete	Close spacing on steep grades Require clean-out Unless keyed at sides and bottom, erosion may occur
Sediment Traps/ Straw Bale Filters 	Can be located as necessary to collect sediment during construction Clean-out often can be done with on-the-job equipment Simple to construct	Little direction on spacing and size Sediment disposal may be difficult Specification must include provisions for periodic clean-out May require seeding, sodding or pavement when removed during final cleanup
Sodding 	Easy to place with a minimum of preparation Can be repaired during construction Immediate protection May be used on sides of paved ditches to provide increased capacity	Requires water during first few weeks Sod not always available Will not withstand high velocity or severe abrasion from sediment load
Seeding with Mulch and Matting 	Usually least expensive Effective for ditches with low velocity Easily placed in small quantities with inexperienced personnel	Will not withstand medium to high velocity
Paving, Riprap, Rubble	Effective for high velocities May be part of the permanent erosion control effort*	Cannot always be placed when needed because of construction traffic and final grading and dressing Initial cost is high
ROADWAY SURFACE		
Crowning to Ditch or Sloping to Single Berm 	Directing the surface water to a prepared or protected ditch minimizes erosion	None - should be part of good construction procedures
Compaction	The final lift of each day's work should be well compacted and bladed to drain to ditch or berm section. Loose or uncompacted material is more subject to erosion	None - should be part of good construction procedures
Aggregate Cover 	Minimizes surface erosion Permits construction traffic during adverse weather May be used as part of permanent base construction	Requires reworking and compaction if exposed for long periods of time Loss of surface aggregates can be anticipated
Seed/Mulch	Minimizes surface erosion	Must be removed or is lost when construction of pavement is commenced

TABLE 3 (Continued)

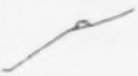
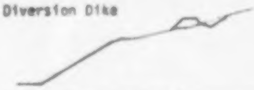
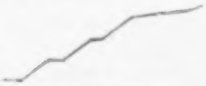
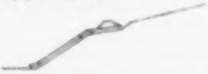
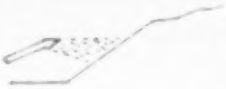
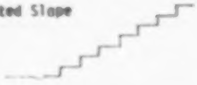
Treatment Practice	Advantages	Problems
CUT SLOPES		
Berm @ top of cut 	Diverts water from cut Collects water for slope drains/paved ditches May be constructed before grading is started	Access to top of cut Difficult to build on steep natural slope or rock surface Concentrates water and may require channel protection or energy dissipation devices Can cause water [illegible]ater ground, resulting in sloughing of the cut slope
Diversion Dike 	Collects and diverts water at a location selected to reduce erosion potential May be incorporated in the permanent project drainage	Access for construction May be continuing maintenance problem if not paved or protected Disturbed material or berm is easily eroded
Slope Benches 	Slows velocity of surface runoff Collects sediment Provides access to slope for seeding, mulching, and maintenance Collects water for slope drains or may divert water to natural ground	May cause sloughing of slopes if water infiltrates Requires additional ROW Not always possible due to rotten material etc. Requires maintenance to be effective Increases excavation quantities
Slope Drains (pipe, paved, etc.) 	Prevents erosion on the slope Can be temporary or part of permanent construction Can be constructed or extended as grading progresses	Requires supporting effort to collect water Permanent construction is not always compatible with other project work Usually requires some type of energy dissipation
Seeding/Mulching 	The end objective is to have a completely grassed slope. Early placement is a step in this direction. The mulch provides temporary erosion protection until grass is rooted. Temporary or permanent seeding may be used. Mulch should be anchored. Larger slopes can be seeded and mulched with smaller equipment if stage techniques are used.	Difficult to schedule high production units for small increments Time of year may be less desirable May require supplemental water Contractor may perform this operation with untrained or unexperienced personnel and inadequate equipment if stage seeding is required
Sodding 	Provides immediate protection Can be used to protect adjacent property from sediment and turbidity	Difficult to place until cut is complete Sod not always available May be expensive
Slope Pavement, Riprap 	Provides immediate protection for high risk areas and under structures May be cast in place or off site	Expensive Difficult to place on high slopes May be difficult to maintain
Temporary Cover	Plastics are available in wide rolls and large sheets that may be used to provide temporary protection for cut or fill slopes Easy to place and remove Useful to protect high risk areas from temporary erosion	Provides only temporary protection Original surface usually requires additional treatment when plastic is removed Must be anchored to prevent wind damage
Serrated Slope 	Lowers velocity of surface runoff Collects sediment Holds moisture Minimizes amount of sediment reaching roadside ditch	May cause minor sloughing if water infiltrates Construction compliance

TABLE 3 (Continued)

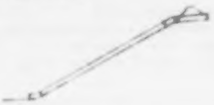
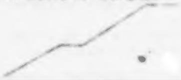
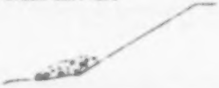
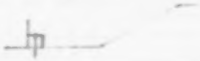
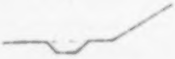
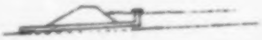
Treatment Practice	Advantages	Problems
FILL SLOPES		
Berms at Top of Embankment	Prevent runoff from embankment surface from flowing over face of fill Collect runoff for slope drains or protected ditch Can be placed as a part of the normal construction operation and incorporated into fill or shoulders	Cooperation of construction operators to place final lifts at edge for shaping into berm Failure to compact outside lift when work is resumed Sediment buildup and berm failure
Slope Drains 	Prevent fill slope erosion caused by embankment surface runoff Can be constructed of full or half section pipe, bituminous, metal, concrete, plastic, or other waterproof material Can be extended as construction progresses May be either temporary or permanent	Permanent construction as needed may not be considered desirable by contractor Removal of temporary drains may disturb growing vegetation Energy dissipation devices are required at the outlets
Fill Berms or Benches 	Slows velocity of slope runoff Collects sediment Provides access for maintenance Collects water for slope drains May utilize waste	Requires additional fill material if waste is not available May cause sloughing Additional ROW may be needed
Seeding/Mulching	Timely application of mulch and seeding decreases the period a slope is subject to severe erosion Mulch that is cut in or otherwise anchored will collect sediment. The furrows made will also hold water and sediment	Seeding season may not be favorable Not 100 percent effective in preventing erision Watering may be necessary Steep slopes or locations with low velocities may require supplemental treatment
PROTECTION OF ADJACENT PROPERTY		
Brush Barriers 	Use slashing and logs from clearing operation Can be covered and seeded rather than removed Eliminates need for burning or disposal off ROW	May be considered unsightly in urban areas
Straw Bale Barriers 	Straw is readily available in many areas When properly installed, they filter sediment and some turbidity from runoff	Require removal Subject to vandal damage Flow is slow through straw requiring considerable area
Sediment Traps 	Collect much of the sediment spill from fill slopes and storm drain ditches Inexpensive Can be cleaned and expanded to meet need	Do not eliminate all sediment and turbidity Space is not always available Must be removed (usually)
Sediment Pools 	Can be designed to handle large volumes of flow Both sediment and turbidity are removed May be incorporated into permanent erosion control plan	Require prior planning, additional ROW and/or flow easement If removal is necessary, can present a major effort during final construction stage Clean-out volumes can be large Access for clean-out not always convenient

TABLE 3 (Continued)

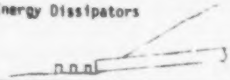
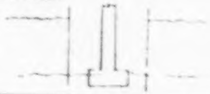
Treatment Practice	Advantages	Problems
PROTECTION OF ADJACENT PROPERTY (continued)		
Energy Dissipators 	Slow velocity to permit sediment collection and to minimize channel erosion off project	Collect debris and require cleaning Require special design and construction of large shot rock or other suitable material from project
Level Spreaders	Convert collected channel or pipe flow back to sheet flow Avoid channel easements and construction off project Simple to construct	Adequate spreader length may not be available Sodding of overflow berm is usually required Must be a part of the permanent erosion control effort Maintenance forces must maintain spreader until no longer required
PROTECTION OF STREAM		
Construction Dike	Permits work to continue during normal stream stages Controlled flooding can be accomplished during periods of inactivity	Usually requires pumping of work site water into sediment pond Subject to erosion from stream and from direct rainfall on dike
Cofferdam 	Work can be continued during most anticipated stream conditions Clear water can be pumped directly back into stream No material deposited in stream	Expensive
Temporary Stream Channel Change	Prepared channel keeps normal flows away from construction	New channel usually will require protection Stream must be returned to old channel and temporary channel refilled
Riprap	Sacked sand with cement or stone easy to stockpile and place Can be installed in increments as needed	Expensive
Temporary Culverts for Haul Roads	Eliminate stream turbulence and turbidity Provide unobstructed passage for fish and other water life Capacity for normal flow can be provided with storm water flowing over the roadway	Space not always available without conflicting with permanent structure work May be expensive, especially for larger sizes of pipe Subject to washout
Rock-lined Low-Level Crossing	Minimizes stream turbidity Inexpensive May also serve as ditch check or sediment trap	May not be fordable during rainstorms During periods of low flow passage of fish may be blocked

TABLE 3 (Concluded)

Treatment Practice	Advantages	Problems
BORROW AREAS		
Selective Grading and Shaping	Water can be directed to minimize off-site damage Flatter slopes enable mulch to be cut into soil	May not be most economical work method for contractor
Stripping and Replacing of Topsoil	Provides better seed bed Conventional equipment can be used to stockpile and spread topsoil	May restrict volume of material that can be obtained for a site Topsoil stockpiles must be located to minimize sediment damage Cost of rehandling material
Dikes, Berms Diversion Ditches Settling Basins Sediment Traps Seeding & Mulch	See other practices	See other practices

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a/ Highway Research Board, "National Cooperative Highway Research Program Synthesis of Highway Practice No. 18, Erosion Control on Highway Construction," Division of Engineering, National Research Council, National Academy of Sciences--National Academy of Engineering, pp. 42-46 (1973).

An excess of water also hastens reduction of soil nitrates, a nutrient, to soil nitrites, a toxin. Too little water, and a plant wilts and dies. A continuous water film around the roots is also necessary to the absorption of 14 of the 16 essential plant nutrients.

When there are no restrictive layers in the soil, and water is adequate, most grasses and legumes that are seeded on soil disturbed by construction activities will usually root to a depth of at least 90 cm (3 ft). On construction fill slopes, the seeded grasses and legumes often have this much soil depth unless they have been compacted excessively. The principal difficulty is encountered on cut slopes where dense natural parent materials often occur.

Seldom does a cut slope have a desirable physical condition to permit plant roots to grow to a depth of 90 cm (3 ft) or 60 cm (2 ft) or even 30 cm (1 ft). The usual recommendations suggest preparing a seed bed on cut slopes to a depth of 10 to 15 cm (4 to 6 in.). On a cut slope, if the seed bed is restricted to a depth of 15 cm (6 in.), this 15-cm (6-in.) depth must be made ideal, both physically and chemically, for seedling germination and plant establishment. This means some kind of mulch must be provided to stabilize the soil surface, capture rainfall, and reduce loss of water by surface evaporation between rains. A physical condition in the soil must be developed to hold and release the right amount of water to plant roots; and void spaces must be maintained to serve as passageways for carbon dioxide and oxygen exchange.

To serve as a "waterproof" foundation for a road, a clay soil should be compacted to a bulk density of at least 1.8, and a sand-clay soil to at least 1.9. Such high soil bulk densities, however, prevent the growth of plants. The ideal bulk density for plant growth on a clay soil is about 1.2 and for a sandy soil about 1.3. Bulk densities greater than 1.4 for a clay soil and 1.6 for a sandy soil generally provide poor seed beds and may restrict plant root growth.*

Preconstruction procedures include sampling the soil in the area of the planned construction. For use in texture (mechanical) analysis as well as for soil nutrient analysis, the usual size of a sample is 2.5 kg (5 lb), 500 g (1 lb) of which can be sent to the laboratory for nutrient testing and 2 kg (4 lb) used for mechanical analysis. Sampling should include the site of the construction area and other sites planned for use as borrow materials and sources of topsoil. All contrasting soil series should be sampled separately to below the depth of planned construction, including foundation footings.

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* Bulk density is the density of the solid soil particles plus the voids between them. The values are ratios in relation to the weight of an equal volume of water. A bulk density of 1.4 means a weight per cubic centimeter of 1.4 g (87.36 lb/ft^3). Soil particle density averages about 2.65 times the weight of an equal volume of water.

Soil sampling procedures for soil nutrient testing may be obtained from any local county extension office, whose office is usually at the county seat, or from the State agricultural university, whose address is in Section V.

1. Soil texture: A soil classified as loam in the USDA system is usually considered ideal for plant growth. Using, as an example, the 0 to 40 cm (0 to 16 in.) soil depth of the Chandler soil series in the Soil Survey of Dawson, Lumkin, and White Counties, Georgia (1972, p. 70) the USDA soil textural class is a loam, the Unified classification is ML, and the American Association of State Highway Officials (AASHO) designation is A-4.

A median loam soil has the following soil separate composition.[1]

Sand - 40%

Silt - 40%

Clay - 20%

In the Unified system, the same Chandler loam is designated ML which means (a) fine-grained soils, inorganic silts, and very fine sands; (b) fine-grained soils with more than 50% retained on a 200-mesh sieve; and (c) plasticity index is low.

Classification according to the system of the AASHO of the same Chandler loam is A-4, more than 35% passing a 200-mesh sieve, fair as a subgrade.

2. Soil structure: Although a loam soil may be texturally satisfactory for plant growth, the structure may or may not be satisfactory.

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[1] In the U.S. Department of Agriculture system, a loam soil varies from less than 52% sand, 28 to 50% silt, and 7 to 27% clay.

Structure refers to the grouping of the individual particles. Natural groups or aggregates are designated as peds and artificially formed aggregates are clods. A soil disturbed by construction activities usually has a minimum of peds and a maximum of clods.

Peds and clods can be classified into three categories as follows:

1. Type (shape and arrangement)
    - Platy (flattened appearance)
    - Blocklike (angular and subangular blocky, resembling baby blocks)
    - Spheroidal (granular, crumb; like imperfect marbles)
2. Glass (size)
    - Fine or thin
    - Medium
    - Coarse
3. Grade (degree of distinctness)
    - Structureless (like loose sand)
    - Weak (indistinctly formed)
    - Strong (well-formed)

3. Soil consistence: Soil consistence refers to the resistance to rupture or deformation of soil clods. The categories depend upon the relative wetness of the clods.

Consistence terms when wet:

- Nonsticky
- Slightly sticky
- Very sticky

Consistence terms when moist:

Loose

Friable

Firm

Consistence terms when dry:

Loose

Soft

Hard

4. Soil depth: On a road cut the ideal loam soil in good physical condition for plant growth could be described as:

At least 15 cm (6 in.) deep to any restricting layer.

Containing approximately 40% sand, 40% silt, and 20% clay.

Having a structure with a spheroidal type, medium class, strong grade, with a friable consistence when moist.

Soils with more than 10% organic matter are designated in the USDA system as mucky or peaty subcategories of the mineral soil textural class. In the Unified system they are designated as OL or OH for organic silts and clays and as Pt for peats and mucks; and for the AASHO system the designation A-8 is used. The percentage of organic matter necessary for making a loam soil an ideal medium for plant growth is approximately 5; however, some State highway departments specify 5 to 20% organic matter as desirable.

To summarize: a loam soil in ideal physical condition for plant growth should, by volume, consist of about one-half solid soil particles (45% mineral and 5% organic), about one-fourth water, and one-fourth air-filled voids. The bulk density of such a soil will be about 1.25 and it will weigh about 1,250 kg/m^3 (78 lb/ft^3) when dry. When moist (as above), a cubic meter of soil will contain 250 kg of water and weigh 1,500 kg (15.6 lb H_2O + 78 lb soil = 93.6 lb/ft^3).

Topsoil parameters for the States of Maryland, Minnesota, and Utah are compared in Table 4. Of the soil separates, only the clay percentage is specified as minimum and maximum by all three States. The minima specified by the three States are 5, 12, and 10%, respectively; whereas, the maxima are 30, 47, and 35% for Maryland, Minnesota, and Utah, respectively. No rationale can be offered for the differences. Maryland specifies a soil pH minimum of 6.0 but no maximum; Utah specifies a minimum pH of 5.5 and a maximum of 8.5. Utah specifies a maximum of 10% exchangeable sodium and a maximum electrical conductivity (as indirect measure of total soluble salts) of 4.0 milliohms.

H. Nutrient Plant Bed Parameters

A respresentative total chemical composition in kilograms per cubic meter (lb/ft^3) will be:

	kg/m^3	lb/ft^3
Silica	1,009	63.0
Alumina	139	8.7
Iron	40	2.5
Potash	22	1.4
Calcium	11	0.7
Magnesium	8	0.5
Phosphorus	2	0.1
Nitrogen	2	0.1
Other	6	1.0
Total	1,250	78.0

Silica and alumina, the most abundant substances in soils, although absorbed by plants, are not essential for plant growth. The essential elements for the growth of all seed-bearing plants and their sources are:

From Air and Water

Hydrogen
Oxygen
Carbon
Nitrogen*

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* Nitrogen comes originally from the air, but plants absorb nitrogen from fixed forms in the soil.

TABLE 4

A COMPARISON OF TOPSOIL CHARACTERISTICS SPECIFIED BY THE HIGHWAY DEPARTMENTS IN MARYLAND, MINNESOTA, AND UTAH[a]

Component/ Characteristic of Soil	Percentage of Soil					
	Minimum			Maximum		
	Maryland	Minnesota	Utah	Maryland	Minnesota	Utah
Gravel	--	--	--	--	--	20
Sand	20	3	--	75	57	65
Silt	10	12	--	60	62	80
Clay	5	12	10	30	47	35
Organic Matter	1.5	--	--	--	--	--
pH	6.0	--	5.5	--	--	8.5
Exchangeable Sodium Percentage	--	--	--	--	--	10
Electrical Conductivity (mohms/cm at 25°C)	--	--	--	--	--	4.0

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[a] (1) Maryland Department of Transportation, "Article 20.26 Topsoil."
(2) Foote, L. E., D. L. Kill, and A. H. Bolland, "Erosion Prevention and Turf Establishment Manual," Office of Materials, Construction Division, Minnesota Department of Highways, 43 pages, p. 22 (1970).
(3) Cook, W. C., I. B. Jensen, G. B. Coltharp, and E. M. Larson, "Seeding Methods for Utah Roadsides," Utah State University Resource Series 52, p. 6, August 1970.

From Soils and Fertilizers

Primary Nutrients

Nitrogen*
Phosphorus
Potassium

Secondary Nutrients

Calcium
Magnesium
Sulfur

Micronutrients

Manganese
Copper
Chlorine
Molybdenum
Zinc
Iron
Boron

Mineral soils below a pH of 6.0 and organic soils below 5.0 should be limed if a legume is included in the seeding mixture. The pH is, however, not the best measure of lime requirement because the reserve soil acidity is ignored. Most soil testing laboratories operated by land-grand universities now use a buffer solution to determine lime requirements. This adequately measures both active and reserve acidity. For adequate availability of all essential soil nutrients, mineral soils should be maintained at a pH of about 6.5 and organic soils 5.5.

Almost all agricultural soils are enhanced by the application of animal manures and chemical fertilizers containing nitrogen, phosphorus, and potassium; soils disturbed by construction activities invariably benefit more from fertilizers because infertile subsoils and substrata often are intermixed. Stockpiling of the A horizon and applying it on the finished slopes can often reduce this difference.

Fertilizer recommendations for agricultural soils are determined by field plot tests supplemented by chemical soil nutrient tests. Disturbed subsoils and substrata must rely on information obtained through the proper sampling of the soil, and analysis and interpretation of their nutrient needs.

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* Nitrogen comes originally from the air, but plants absorb nitrogen from fixed forms in the soil.

Soil testing in the 50 States for available plant nutrients now totals almost 4 million samples a year. In general, the tests indicate a decreasing supply of available nutrients with depth. The deeper the disturbance of soils by construction activities and the more the intermixing of materials, the more essential it is to collect more soil samples for fertility testing. By liming and fertilizing according to the results of soil tests, a uniform and vigorous stand of vegetation can usually be established quickly on soils and underlying parent materials which have been disturbed by construction activities.

Fertilizers applied immediately prior to the seeding of adapted vegetation will facilitate rapid establishment. Documentation of this effect is scare; however, the Minnesota Department of Highways has some evidence covering the period of May 1959 to August 1961 which substantiates it. Based upon the relative percentage of ground cover, a seeding, fertilized according to the results of a soil test, had a cover percentage between 80 and 90, whereas an unfertilized seeding on a similar soil had a ground cover of 70% in 1959 and between 75 and 80% during 1960 and 1961. Since rapid establishment is more important in erosion control on disturbed soils, fertilizers were credited with more than a 15% increase in ground cover during the first year (Figure 13).

Fertilizing a construction site according to a soil test assures that essential elements will be available to the plants in a balanced ratio; it also assures the most efficient expenditure of money for fertilizer, and that a minimum of excess fertilizer will pollute the water environment.

I. Sediment Control and Urbanization

On construction sites, raindrops strike bare soil and alter its surface properties. Voids and cracks through which water moves are sealed, thus reducing infiltration and increasing runoff and erosion. Any surface covering material, living or nonliving, reduces the impact of the raindrop, encourages soil-burrowing members of the animal kingdom, and increases infiltration. The gross result is more water in the soil available for plant growth and less runoff sediment into streams.

Before man's disturbing activities began, soil material on upper slopes in the United States probably eroded at about the same rate as soil profiles were formed from parent material, i.e., at about the rate of 560 kg/ha/year (500 lb/acre/year).

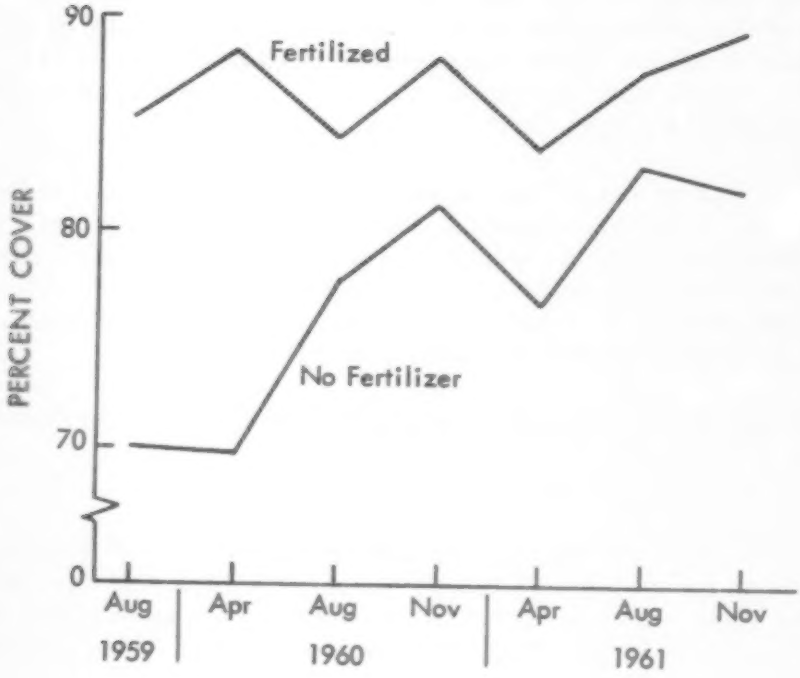

Figure 13 - Fertilizing a New Seeding According to the Results of a Soil Test Increases Plant Density by 15% the 1st Year and by More than 5% the Following 2 Years; Foote, L. E., D. L. Kill, and A. H. Bolland, "Erosion Prevention and Turf Establishment Manual," Office of Materials, Construction Division, Minnesota Department of Highways, 43 pages, p. 18 (1970).

As a consequence of man's use and abuse of upper slopes, erosion is now more rapid. For example, in the entire Mississippi River Basin, soils presently erode at twice the natural geologic rates--at 1,100 kg/ha/year (1,000 lb/acre/year).[1] Soils in present-day forests are now eroding at this same rate. Soils used for pastures in northern Mississippi erode at the rate of about 3,400 kg/ha (3,000 lb/acre), and cultivated fields in the same area 47,000 kg/ha/year (42,000 lb/acre/year). In the same watershed, the ratios of erosion of Geologic:Forest:Pasture:Cropland are: 1:2:6:84 (Figure 14a).

In an urbanizing watershed in Fairfax County, Virginia, construction of highways resulted in an annual yeild of slightly more than 110,000 kg/ha (100,000 lb/acre); and urban developments in Kensington, Maryland, were responsible for a yield of more than 170,000 kg/ha (150,000 lb/acre). These rates, compared with the foregoing rates of erosion, result in the following comparative ratios:

Geologic:Forest:Pasture:Cropland:Highway Construction:Urbanization.

1 : 2 : 6 : 84 : 200 : 300.

Sediment yields from urbanizing areas under construction have been reported as high as 340,000 kg/ha/year (310,000 lb/acre/year).[2] At the other extreme, yields of less than 3,400 kg/ha/year (3,100 lb/acre/year) may result from urbanization when all known criteria for control are applied (Figure 14a).

The National Atlas of the United States lists the total area of the United States as 9,170,983 km^2 (3,540,920 miles^2), used approximately as follows:

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[1] Dow Chemical Company, Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization, Midland, Michigan, 181 pages (1972).

[2] Guy, H. P., and D. E. Jones, Jr., "Urban Sedimentation--In Perspective," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, No. 9420 HY12, pp. 2099-2116, December 1972.

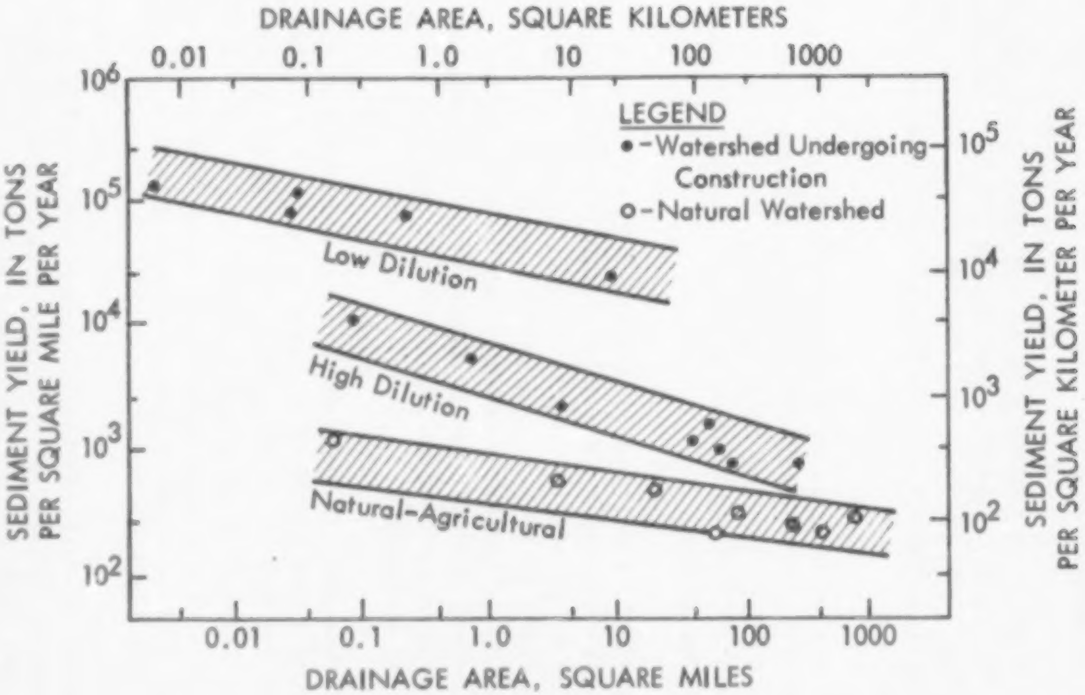

Figure 14a - Effect of Construction Intensity and Drainage Area on Sediment Yield (Most of data are from Baltimore and Washington, D.C., metropolitan areas. Term dilution refers to drainage from relatively stable nonconstruction areas.)

83% - Forests, rangelands, mountains and deserts

13% - Cropland

2.5% - Urban areas

1.1% - Highways and roads

Urban areas occupy about 2.5% of the total land area of the United States. This percentage is equal to 229,275 km^2 (88,523 miles^2). A very rough estimate places the percentage of total land of the United States that is being disturbed by urbanization each year at 0.04% (3,668 km^2)(1,416 miles^2).

The effective control of sediment runoff from urbanizing areas, as viewed by agriculturists, is to "establish a pasture on them." Stated in another way, the planner, the developer, the contractor, and the "pasture specialist," must coordinate their efforts at all stages of planning and implementation.

The cardinal principles of sediment control include: slope grade reduction for more rapid vegetation establishment; selection of acceptable species of grasses, legumes, shrubs, and trees; application of lime and fertilizer as specified by a soil test; use of a mulch; seeding and planting during the most favorable season; watering if necessary to establish a stand; and periodic inspection and maintenance. When vegetation alone is not feasible to control sediment yields, suitable structures may be needed.

Design criteria for soil erosion and sediment control applicable to urbanizing areas in the State of Maryland are detailed by the Soil Conservation Service.[1] Similar criteria for critical area stabilization on urban construction sites may be obtained from the resident District Conservationist of the U.S. Soil Conservation Service. In forested areas, additional sources of expertise are the respective State forester and the personnel of the U.S. Forest Service.

The objective in establishing vegetation on soils disturbed by construction activities should be to reduce erosion and sediment yield to at least the rate from pasturelands, or 3,400 kg/ha/year (3,000 lb/acre/year). In essence, this means the establishment of a vegetative cover on disturbed soils that is as protective as pasture swards.

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[1] Soil Conservation Service, U.S. Department of Agriculture, "Standards and Specifications for Soil Erosion and Sediment Control in Urbanizing Areas," variously paged, November 1969.

Meiman[1] has developed a generalized line graph showing the relationship between density of vegetative ground cover and yield of sediment to streams (Figure 14b). From this graph it can be concluded that sediment is effectively stabilized only when the ground cover density is greater than 50%; and that a ground cover of 15% or less is no better than bare soil.

J. Seed and Plant Selection

The selection of plant species for a particular site will depend upon a list of adapted plants that have the desired characteristics. According to the system presented in Figure 15,[2] parameters, classification, and examples of grasses and legumes are shown.

The State and Federal seed laws require that each lot of seed offered for sale shall be packaged and labeled, and that the labels show:

1. Percentage of pure seed;
2. Percentage of weed seeds, including noxious weeds;
3. Percentage of other crop seeds;
4. Percentage of inert matter;
5. Percentage of hard seeds;
6. Percentage of viable seeds;
7. Date of germination test;
8. Name and address of shipper, seller, or person who labeled the seeds; and
9. Net weight of seeds.

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[1] Meiman, J. R., "Water and Erosion Control in Relation to Revegetation of High-Altitude Disturbed Lands," In: Revegetation of High-Altitude Disturbed Lands, pp. 24-30, Proceedings of a Workshop at Ft. Collins, Colorado, 31 January through 1 February 1974.

[2] Foote, L. E., D. L. Kill, and A. H. Bolland, Erosion Prevention and Turf Establishment Manual, Minnesota Department of Highways, pp. 13 and 14 (1970).

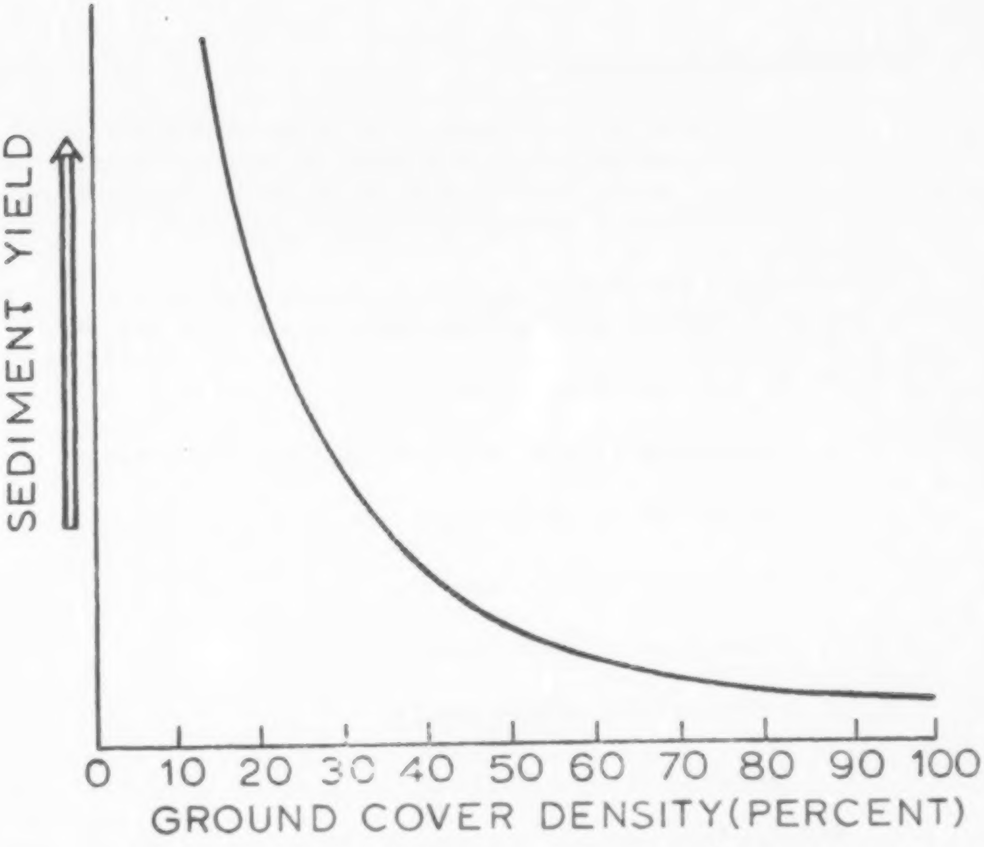

Figure 14b - Generalized Schematic Diagram of Sediment Yield as a Function of Ground Cover Density

Parameter	Classification		Examples
Texture	fine		Kentucky bluegrass, bentgrass, red fescue
	coarse		Smooth bromegrass, reed canarygrass, timothy
Growth, height	short		Buffalograss, Kentucky bluegrass, red fescue
	medium		Redtop, perennial ryegrass
	tall		Smooth bromegrass, timothy, switchgrass
Growth, turf	bunch		Timothy, big bluestem, sand dropseed, perennial ryegrass
	sod former		Quackgrass, smooth bromegrass, Kentucky bluegrass, switchgrass
Origin	Introduced		Smooth bromegrass, Kentucky bluegrass, alfalfa, white clover.
	Native		Switchgrass, big bluestem, sand dropseed.
Way of Spread	Seed		Red clover, alsike, sand dropseed, rye, perennial ryegrass, field bromegrass.
	Vegetatively		Prairie cordgrass, some bentgrasses.
	Both		White clover, crownvetch, quackgrass, Kentucky bluegrass, smooth bromegrass.
Life	Annual	Summer	Corn, sorghum, rabbit clover, oats, soybeans.
		Winter	Rye, hairy vetch, field bromegrass.
	Biennial		Sweetclover.
	Perennial	Long-lived	Birdsfoot trefoil, crownvetch, Kentucky bluegrass, smooth bromegrass.
		Short-lived	Timothy, perennial ryegrass, red clover, white clover.
Establishment	Hard		Big bluestem, crownvetch.
	Medium		Perennial ryegrass, smooth bromegrass.
	Easy		Rye, oats.
Maintenance	Hard		Tall fescue, reed canarygrass.
	Medium		Kentucky bluegrass, smooth bromegrass.
	Easy		Crownvetch, white clover.
To Maintain Stand	Hard		Timothy, alfalfa, perennial ryegrass.
	Medium		Kentucky bluegrass, white clover.
	Easy		Birdsfoot trefoil, crownvetch, big bluestem, switchgrass, reed canarygrass.
Root System	Shallow	Strong	Timothy, Kentucky bluegrass
		Weak	Sand dropseed, crabgrass, foxtail, white clover.
	Deep	Strong	Alfalfa, big bluestem, switchgrass, reed canarygrass.
		Weak	Many weeds.

Figure 15 - Parameters and Examples of Classifying Grasses and Legumes

Seeds of many grasses should be treated with suitable chemicals to control the fungus disease "damping-off" and to improve germination and early seedling survival. Certain smut diseases on such grasses as the millets, slender wheatgrass, Canada wild rye, and sudangrass can be controlled by seed treatment prior to seeding. Seed treatment can also protect seeds against certain insects.

Many legume seeds should be scarified, scratched, to break their impermeable seed coat and thus hasten absorption of water and germination. All legume seeds should be treated not more than 24 hr prior to seeding with the exact type of bacterial inoculum to supply the proper microbes for symbiotic nitrogen fixation. Large batches of seed-containing legumes can be mixed with inoculum in a cement mixer. When legume seeds are to be sown with a hydroseeder, the Kentucky Department of Transportation[1/] recommends the use of five times the normal amount of inoculant as suggested by the manufacturer.

The following characteristics of plants should be considered in selecting species for planting on disturbed soils, as proposed by Jackobs et al.[2/] for highways.

1. Plants must have the proven ability to thrive under the conditions of the site where they are proposed to be established, such as steep, dry, sandy, clayey, wet, salty, alkali, or acid areas.

2. Plants that are low-growing and spread from rhizomes or stolons should be given preference.

3. Rapidly developing plants should be given preference over those that become established slowly, especially on highly erosive soils.

4. Resistance to fire or the ability to recover quickly after a fire are necessary attributes.

1/ Kentucky Department of Transportation, Bureau of Highways, Special Provision No. 46-D, Water Pollution Control, Frankfort, Kentucky, 8 pages, p. 3, January 1973.

2/ Jackobs, J. A., O. N. Andrews, Jr., C. L. Murdock, and L. E. Foote, "Turf Establishment on Highway Right-of-Way Slopes--A Review," University of Illinois Agronomy Series No. 77 (1967).

5. Plants should be as resistant as possible to insects and diseases.

6. Plants that are not palatable to wild or domestic animals should be given preference over those that are.

7. Plants that are likely to escape and become a noxious weed in cultivated fields should not be used in farming areas.

8. Poisonous plants should not be planted.

Specific selection of plants species to seed or plant on disturbed soils has been made in the past in the following ways:

1. Buying whatever seed mixture is available on the open market at the time the seeds are needed.

2. Ordering the mixtures or plants from a reputable supplier several months in advance of seeding and planting time.

3. Following the recommendations of the Agricultural Experiment Station, the Extension Service, or the District Soil Conservationist of the respective States (Figure 16).

The Soil Conservation Service operates 21 plant materials centers in the United States that receive and evaluate foreign plants introduced by the Agricultural Research Service of the United States Department of Agriculture (Section V-G). The Centers also collect and test potential seeds and plants from the United States. As stated in the Federal Register,[1/] "The emphasis of the SCS plant materials work is to find suitable plants for erosion control adapted to soil and site conditions where it is difficult to establish vegetation." The soil and site conditions encountered in eroded areas many times are similar to those disturbed by construction activities. The seeding and planting techniques should also be similar.

Seed and plant recommendations in SCS Technical Guides are made on an area basis through the use of the "Land Resource Regions and

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[1/] Federal Register, 39(75):13784, 17 April 1974.

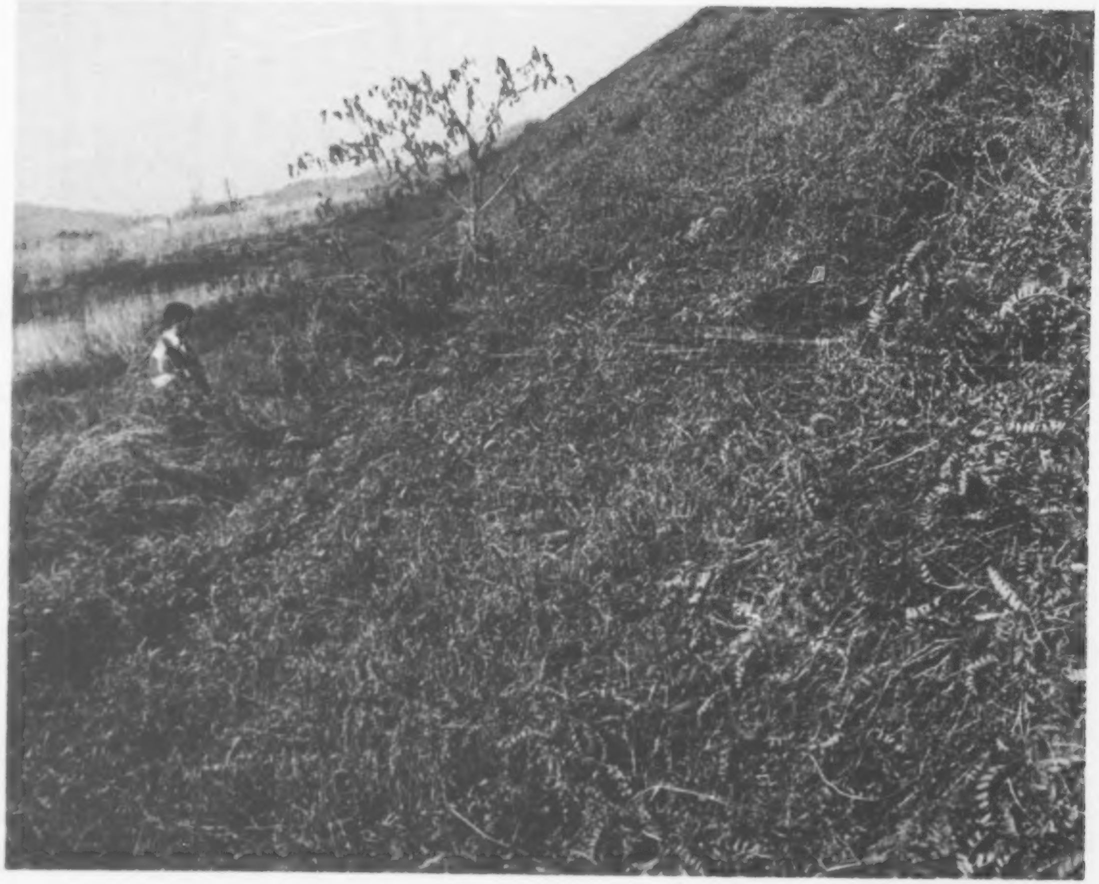

Figure 16 - The Original Seeding Had Failed on This Fill Slope. The roadside was again fertilized and reseeded with a recommended seed mixture. This photo was taken 1 year later (West Virginia). (Courtesy of Roy Blaser)

Major Land Resource Areas of the United States (exclusive of Alaska and Hawaii),"[1] presented in Figure 17 and the legend that follows.

K. Seeding, Planting, and Sodding

Probably the most critical of all decisions in the successful establishment of vegetation on soils disturbed by construction activities is the time of seeding.

Seed and seeding data for grasses, forbs and legumes, and shrubs adapted to the 17 western States are tabulated in Section V-L, followed by characteristics and seeding recommendations for grasses and legumes adapted to the midwestern United States in Section V-M.

Tree and shrub planting guidelines are summarized by the Bureau of Land Management.[2] Trees and shrubs planted alone are not effective immediately in reducing erosion sediment yield; they are, however, recommended under these conditions:

1. When planted in conjunction with a surface mulch such as woodchips.

2. When a perennial seeding mixture is used on the same area as the trees and shrubs.

3. When the area is naturally a forest environment.

Trees and shrubs are not recommended on highways where they obstruct the view of motorists.

Sodding in lieu of seeding is usually the recommended practice to protect the soil from erosion on new construction sites on steep slopes and around culverts, especially in urban areas. Sprigging refers to the planting of pieces of certain grasses that reproduce by underground stolons or above-ground runners, such as bermuda grass.

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[1] Austin, M. E., "Land Resource Regions and Major Land Resource Areas of the United States (exclusive of Alaska and Hawaii)," U.S. Department of Agriculture, Soil Conservation Service, Agriculture Handbook 296, 82 pages (1965). Note: As of September 1974, this Handbook was being revised for a predicted publication date of 1976.

[2] Bureau of Land Management, U.S. Department of the Interior, Manual Transmittal Sheet No. 7414, "Tree and Shrub Planting," Release 7-11, dated 11 October 1968.

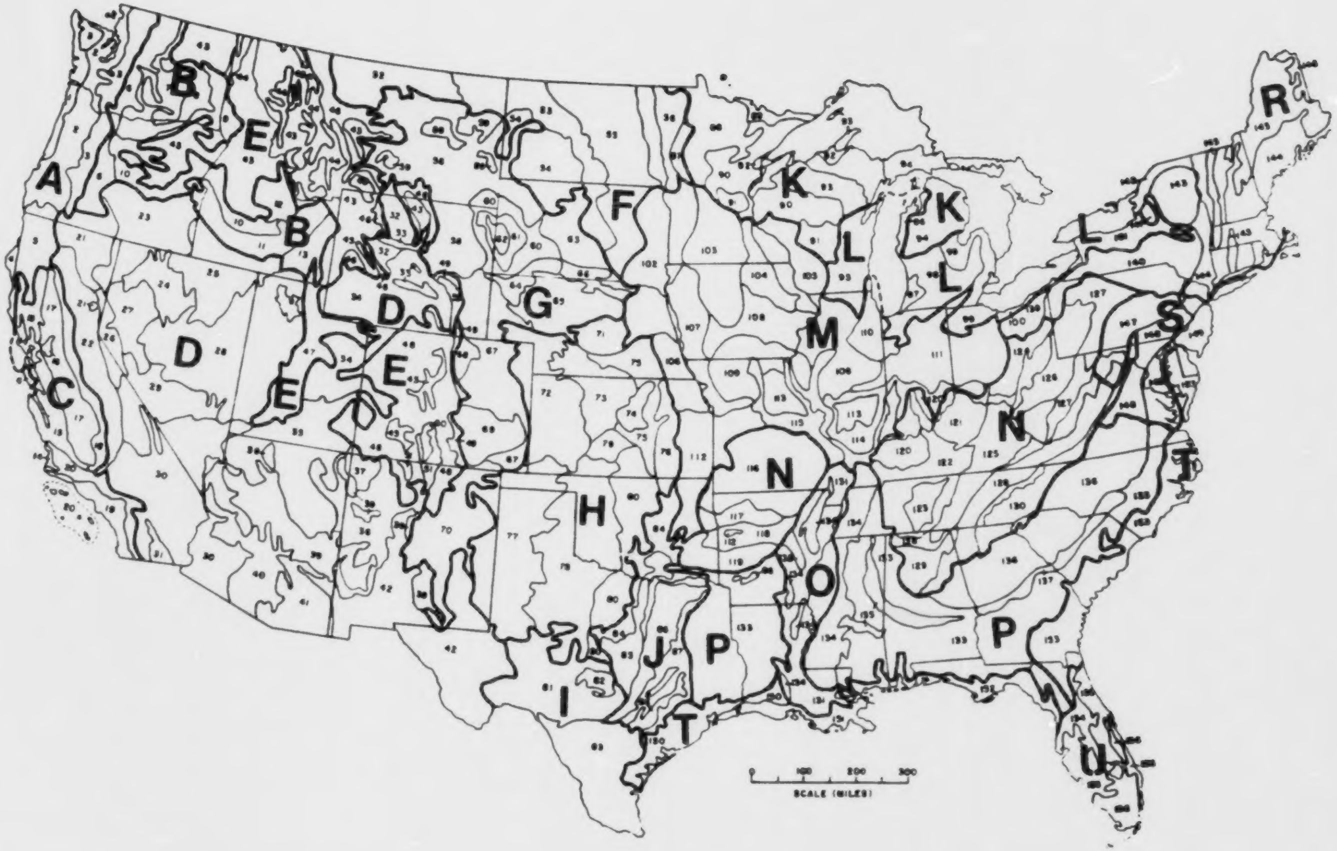
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Figure 17 - Land Resource Regions and Major Land Resource Areas of the United States (exclusive of Alaska and Hawaii)

A. NORTHWESTERN FOREST, FORAGE, AND SPECIALTY CROP REGION

1. Northern Pacific Coast Range and Valleys
2. Williamette and Puget Sound Valleys
3. Olympic and Cascade Mountains (Western Slope)
4. California Coastal Redwood Belt
5. Siskiyou - Trinity Area

B. NORTHWESTERN WHEAT AND RANGE REGION

6. Cascade Mountains (Eastern Slope)
7. Columbia Basin
8. Columbia Plateau
9. Palouse and Nez Perce Prairies
10. Upper Snake River Lava Plains and Hills
11. Snake River Plains
12. Lost River Valleys and Mountains
13. Eastern Idaho Plateaus

C. CALIFORNIA SUBTROPICAL FRUIT, TRUCK, AND SPECIALTY CROP REGION

14. Central California Valleys
15. Central California Coast Range
16. California Delta
17. Sacramento and San Joaquin Valleys
18. Sierra Nevada Foothills
19. Southern California Coastal Plain
20. Southern California Mountains

D. WESTERN RANGE AND IRRIGATED REGION

21. Klamath and Shasta Valleys and Basins
22. Sierra Nevada Range
23. Malheur High Plateau
24. Humboldt Area
25. Owyhee High Plateau
26. Carson Basin and Mountains
27. Fallon - Lovelock Area
28. Great Salt Lake Area
29. Southern Nevada Basin and Range
30. Sonoran Basin and Range
31. Imperial Valley
32. Northern Intermountain Desertic Basins
33. Semiarid Rocky Mountains
34. Central Desertic Basins, Mountains, and Plateaus
49. (See E)

35. Colorado and Green Rivers Plateaus
36. New Mexico and Arizona Plateaus and Mesas
37. San Juan River Valley Mesas and Plateaus
38. Black, Hualpai, and Cerbat Mountains
39. Arizona and New Mexico Mountains
40. Central Arizona Basin and Range
41. Southeastern Arizona Basin and Range
42. Southern Desertic Basins, Plains, and Mountains

E. ROCKY MOUNTAIN RANGE AND FOREST REGION

43. Northern Rocky Mountains
44. Northern Rocky Mountain Valleys
45. Alpine Meadows and Rockland
46. Northern Rocky Mountain Foothills
47. Wasatch and Uinta Mountains
48. Southern Rocky Mountains
49. Southern Rocky Mountain Foothills
50. San Luis Valley
51. High Intermountain Valleys

F. NORTHERN GREAT PLAINS SPRING WHEAT REGION

52. Brown Glaciated Plain
53. Dark Brown Glaciated Plain
54. Rolling Soft Shale Plain
55. Black Glaciated Plains
56. Red River Valley of the North
57. Western Minnesota Forest - Prairie Transition

G. WESTERN GREAT PLAINS RANGE AND IRRIGATED REGION

58. Northern Rolling High Plains
59. Northern Smooth High Plains
60. Pierre Shale Plains and Badlands
61. Black Hills Foot Slopes
62. Black Hills
63. Rolling Pierre Shale Plains
64. Mixed Sandy and Silty Tableland
65. Nebraska Sand Hills
66. Dakota - Nebraska Eroded Tableland
67. Central High Plains
68. Irrigated Upper Platte River Valley
69. Upper Arkansas Valley Rolling Plains
70. Pecos - Canadian Plains and Valleys

H. CENTRAL GREAT PLAINS WINTER WHEAT AND RANGE REGION

71. Central Nebraska Loess Hills
72. Central High Tableland
73. Rolling Plains and Breaks
74. Central Kansas Sandstone Hills
75. Central Loess Plains
76. Bluestem Hills
77. Southern High Plains
78. Central Rolling Red Plains
79. Great Bend Sand Plains
80. Central Rolling Red Prairies

I. SOUTHWESTERN PLATEAUS AND PLAINS RANGE AND COTTON REGION

81. Edwards Plateau
82. Texas Central Basin
83. Rio Grande Plain

J. SOUTHWESTERN PRAIRIES COTTON AND FORAGE REGION

84. Cross Timbers
85. Grand Prairie
86. Texas Blackland Prairie
87. Texas Claypan Area

K. NORTHERN LAKE STATES FOREST AND FORAGE REGION

88. Northern Minnesota Swamps and Lakes
89. Minnesota Rockland Hills
90. Central Wisconsin and Minnesota Thin Loess and Till
91. Wisconsin and Minnesota Sandy Outwash
92. Superior Lake Plain
93. Northern Michigan and Wisconsin Stony, Sandy, and Rocky Plains and Hills
94. Northern Michigan Sandy Drift

L. LAKE STATES FRUIT, TRUCK, AND DAIRY REGION

95. Southeastern Wisconsin Drift Plain
96. Western Michigan Fruit Belt
97. Southwestern Michigan Fruit and Truck Belt
98. Southern Michigan Drift Plain
99. Erie - Huron Lake Plain
100. Erie Fruit and Truck Area
101. Ontario - Mohawk Plain

M. CENTRAL FEED GRAINS AND LIVESTOCK REGION

102. Loess, Till, and Sandy Prairies
103. Central Iowa and Minnesota Till Prairies
104. Eastern Iowa and Minnesota Till Prairies
105. Northern Mississippi Valley Loess Hills
106. Nebraska and Kansas Loess - Drift Hills
107. Iowa and Missouri Deep Loess Hills
108. Illinois and Iowa Deep Loess and Drift
109. Iowa and Missouri Heavy Till Plain
110. Northern Illinois and Indiana Heavy Till Plain
111. Indiana and Ohio Till Plain
112. Cherokee Prairies
113. Central Claypan Areas
114. Southern Illinois and Indiana Thin Loess and Till Plain
115. Central Mississippi Valley Wooded Slopes

N. EAST AND CENTRAL GENERAL FARMING AND FOREST REGION

112. (See M)
116. Ozark Highland
117. Boston Mountains
118. Arkansas Valley and Ridges
119. Ouachita Mountains
120. Kentucky and Indiana Sandstone and Shale Hills and Valleys
121. Kentucky Bluegrass
122. Highland Rim and Pennyroyal
123. Nashville Basin
124. Western Allegheny Plateau
125. Cumberland Plateau and Mountains
126. Central Allegheny Plateau
127. Eastern Allegheny Plateau and Mountains
128. Southern Appalachian Ridges and Valleys
129. Sand Mountain
130. Blue Ridge

O. MISSISSIPPI DELTA COTTON AND FEED GRAINS REGION

131. Southern Mississippi Valley Alluvium
132. Eastern Arkansas Prairies
134. (See P)

P. SOUTH ATLANTIC AND GULF SLOPE CASH CROP, FOREST, AND LIVESTOCK REGION

86. (See J)
133. Southern Coastal Plain
134. Southern Mississippi Valley Silty Uplands
135. Alabama and Mississippi Valley Silty Uplands
136. Southern Piedmont
137. Carolina and Georgia Sand Hills
138. North - Central Florida Ridge

R. NORTHEASTERN FORAGE AND FOREST REGION

139. Eastern Ohio Till Plain
140. Glaciated Allegheny Plateau and Catskill Mountains
141. Tughill Plateau
142. St. Lawrence - Champlain Plain
143. Northeastern Mountains
144. New England and Eastern New York Upland
145. Connecticut Valley
146. Aroostook Area

S. NORTHERN ATLANTIC SLOPE TRUCK, FRUIT, AND POULTRY REGION

147. Northern Appalachian Ridges and Valleys
148. Northern Piedmont
149. Northern Coastal Plain

T. ATLANTIC AND GULF COAST LOWLAND FOREST AND TRUCK CROP REGION

150. Gulf Coast Prairies
151. Gulf Coast Marsh
152. Gulf Coast Flatwoods
153. Atlantic Coast Flatwoods

U. FLORIDA SUBTROPICAL FRUIT, TRUCK CROP, AND RANGE REGION

154. South - Central Florida Ridge
155. Southern Florida Flatwoods
156. Florida Everglades and Associated Areas

L. Mulches

On all sloping areas disturbed by construction activities some types of mulch is generally needed to stabilize the soil until seedlings become well established.

The word "mulch" according to the Soil Science Society of America means, "(i) Any material such as straw, sawdust, leaves, plastic film, loose soil, etc., that is spread upon the surface of the soil to protect the soil and plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc. (ii) To apply mulch to the soil surface."

Mulches are used primarily to protect exposed soil surfaces from erosion activity. A soft and protective mulch may be provided by almost any organic or inorganic materials that are not toxic to plants. The most common substances used for mulches are straw, hay, woodchips, and gravel. Straw and hay on steep slopes may be "tacked" down by disking or with an asphalt spray.

Some mulches, such as a thin layer of asphalt or latex emulsion, form waterproof surfaces that control erosion but do not permit the establishment of vegetation. Some resin mulches are porous enough to assist in "nursing" vegetation, but are effective only on coarse-textured soil and geological materials. Even the effective rate of application of hay and straw on steep slopes is governed by soil fineness; on clay soil, more organic mulch is required (Figure 18).

M. Maintenance of Vegetation

Even though vegetation is well established on construction sites, it needs constant maintenance. Weeds will invade, insects will appear, careless motorists will puncture the turf, fire may kill and "weak" spots will develop. Herbicides and a mowing schedule will control weeds; dusts and sprays will control insects; weak spots can be renovated, relimed (if necessary), refertilized, and reseeded; but careless motorists must be tolerated. Dusting or spraying of herbicides should be done on a spot basis because of the hazard of killing legumes in the turf. The use of both herbicides and insecticides may be a hazard to the environment.

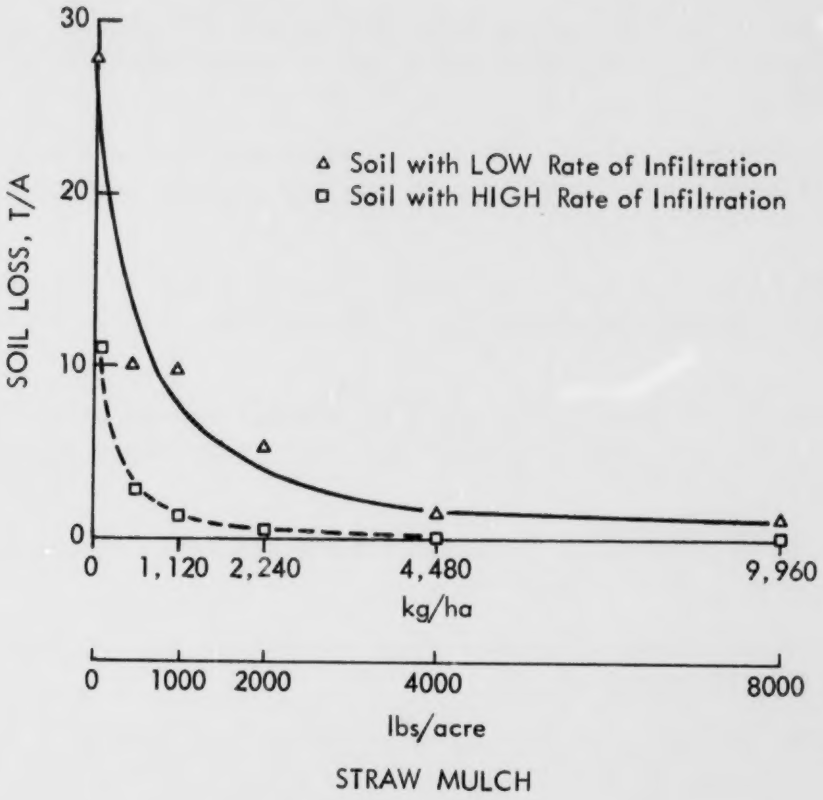

Figure 18 - Soil Loss on Two Soils with Different Rates of Infiltration as Related to Straw Mulch Rates[1/]

[1/] Myer, L. D., et al., "Mulch Rates Required for Erosion Control on Steep Slopes," Soil Science Society of America Proceedings, 34:948-931 (1970).

N. Additional References

Anderson, D. G., "Effects of Urban Development on Floods in Northern Virginia," U.S. Geological Survey open-file report, 26 pages (1968).

Anderson, D. G., "Effects on Urban Development on Floods in Northern Virginia," U.S. Geological Survey Water-Supply Paper 2001-C, 22 pages (1970).

Anderson, P. W., and J. E. McCall, "Urbanization's Effect on Sediment Yield in New Jersey," *Journal of Soil and Water Conservation*, **23**(4): 142-144 (1968).

Bailey, R. W., "Land Erosion--Normal and Accelerated in the Semi-Arid West," *American Geophysical Union Transactions*, Part 2, pp. 240-250 (1941).

Bennett, H. H., and W. C. Lowdermilk, "General Aspects of the Soil-Erosion Problem in Soils and Men," *U.S. Department of Agriculture Yearbook*, pp. 581-608 (1938).

Busby, C. E., "Some Legal Aspects of Sedimentation," *Transactions ASCE*, **127**, Part I, 1007-1044 (1962).

Busby, C. E., "Aspects of American Sedimentation Law," *Journal of Soil and Water Conservation*, **22**(3):107-109 (1967).

Davis, R. K., and D. B. Brooks, "Economic Aspects of Urban Sedimentation," *Land Economy*, **47**:312-319 (1967).

Dawdy, D. R., "Knowledge of Sedimentation in Urban Environments," *Journal of the Hydraulics Division*, ASCE, **93**, No. HY6, Proc. Paper 5595, pp. 235-245, November 1967.

Dragoun, F. J., "Rainfall Energy as Related to Sediment Yield," *Journal of Geophysical Research*, **67**(4):1495-1501 (1962).

"Erosion and Sediment Control on Urban and Construction Sites--An Annotated Bibliography," American Society of Agricultural Engineers, St. Joseph, Michigan, 13 pages (1972).

Farvar, M. T., "The Unforeseen International Ecological Boomerang," Natural History, 78(2):41-72 (1968).

Guy, H. P., "Residential Construction and Sedimentation at Kensington, Maryland," Proceedings, Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, U.S. Department of Agriculture, Misc. Pub. 970, pp. 30-37 (1963).

Guy, H. P., "Research Needs Regarding Sediment and Urbanization," Journal of the Hydraulics Division, ASCE, 93, No. HY6, Proc. Paper 5596, pp. 247-254, November 1967.

Guy, H. P., "Sediment Problems in Urban Areas," U.S. Geological Survey Circular 601-E, 8 pages (1970).

Guy, H. P., and G. E. Ferguson, "Sediment in Small Reservoirs Due to Urbanization," Journal of the Hydraulics Division, ASCE, 88, No. HY2, Proc. Paper 3070, pp. 27-37, March 1962.

Guy, H. P., and G. E. Ferguson, "Sedimentation as an Environmental Problem," Journal of Soil and Water Conservation, 25(6):217-221 (1970).

Guy, H. P., et al., "A Program for Sediment Control in the Washington Metropolitan Region," Washington, D.C., Interstate Commission Potomac River Basin, 48 pages, May 1963.

Hawkins, A. C., "Maryland's Sediment Control Law," Journal of Soil and Water Conservation, 26(1):28-29 (1971).

Johnson, C. J., "Urban Sediment Can Be Controlled," Proceedings, Interstate Commission on the Potomac River Basin, Washington, D.C., 40 pages, (1966).

Jones, D. E., Jr., "Urban Hydrology--A Redirection," Civil Engineering, ASCE, 37(8):58-62, August 1967.

Jones, D. E., Jr., "Where is Urban Hydrology Practice Today?," Journal of the Hydraulics Division, ASCE, 97, No. HY2, Proc. Paper 7917, pp. 257-264, February 1971.

Keller, F. J., "Effect of Urban Growth on Sediment Discharge," Northwest Branch Anacostia River Basin, Maryland, U.S. Geological Survey Professional Paper 450C, pp. 129-131 (1962).

"Landscape for Living," U.S. Department of Agriculture, *Yearbook of Agriculture*, 376 pages (1972).

Leopold, L. B., "Hydrology for Urban Land Planning--A Guidebook on the Hydrologic Effects of Urban Land Use," U.S. Geological Survey Circular 554, 18 pages (1968).

Middleton, H. E., "Properties of Soils Which Influence Soil Erosion," U.S. Department of Agriculture, Technical Bulletin 178, 16 pages (1930).

Mutchler, C. K., "Parameters for Describing Raindrop Splash," *Journal of Soil and Water Conservation*, **22**(3):91-94 (1967).

Mutchler, C. K., and C. L. Larson, "Splash Amounts from Waterdrop Impact on a Smooth Surface," *Water Resources Research*, **7**(1):195-200 (1971).

Osborn, B., "Soil Splash by Raindrop Impact on Bare Soils," *Journal of Soil and Water Conservation*, **9**(1):33-49 (1954).

Peele, T. C., "The Relation of Certain Physical Characteristics to the Erodibility of Soils," *Proceedings*, Soil Science Society of America, **2**:97-100 (1937).

Powell, M. D., W. C. Winter, and W. P. Bodwitch, Community Action Guidebook for Soil Erosion and Sediment Control, National Association of Counties Research Foundation, 64 pages (1970).

Proceedings of the National Conference on Sediment Control, Department of Housing and Urban Development, Washington, D.C., 14 September through 16 September 1969.

"Processes, Procedures, and Methods to Control Pollution Resulting from All Construction Activity " U.S. Environmental Protection Agency, EPA 430/9-73-007, 234 pages, October 1973.

Reed, L. A., "Hydrology and Sedimentation of Corey Creek and Elk River Basins, North Central Pennsylvania," U.S. Geological Survey Water-Supply Paper 1532-E, 27 pages (1971).

Roalman, A. R., "A Bounty on Water Polluters," *Water Resources Bulletin*, American Water Resources Association, Urbana, Illinois, **5**(2):62-65 (1969).

Roehl, J. W., "Sediment Source Areas, Delivery Ratios, and Influencing Morphological Factors," International Association of Scientific Hydrology, Publication 59, pp. 202-213 (1962).

Sediment Control Manual, Baltimore County, Maryland: Baltimore County's Standards, Specifications and Design Manual, Baltimore, Maryland (1970).

"Sediment Sources and Sediment Yields," by the Task Committee on Preparation of Sedimentation Manual, Committee on Sedimentation of the Hydraulics Division, Journal of the Hydraulics Division, ASCE, **96**, No. HY6, Proc. Paper 7337, pp. 1283-1329, June 1970.

Thompson, J. R., "Soil Erosion in the Detroit Metropolitan Area," Journal of Soil and Water Conservation, **25**(1):8-10 (1970).

Turner, D. J., "Dams and Ecology: Can They Be Made Compatable?," Civil Engineering, ASCE, **41**(9):76-80, September 1971.

Vice, R. B., H. P. Guy, and G. E. Ferguson, "Sediment Movement in an Area of Suburban Highway Construction," Scott Run Basin, Fairfax County, Virginia, 1961-1964, U.S. Geological Survey Water-Supply Paper 1591-E, 41 pages (1969).

Wark, J. W., and F. J. Keller, "Preliminary Study of Sediment Sources and Transport in the Potomac River Basin," Technical Bulletin 1963-11, Interstate Commission on the Potomac River Basin, Washington, D.C., 28 pages (1963).

"Water Pollution Aspects of Urban Runoff," American Public Works Association, Federal Water Pollution Control Administration, WP-20-15, 272 pages (1969).

Williams, G. P., and H. P. Guy, "Debris Avalanches--A Geomorphic Hazard," Environmental Geomorphology, D. Coates, ed., State University of New York, Binghamton, New York, pp. 25-46 (1971).

Wischmeier, W. H., C. B. Johnson, and B. V. Cross, "A Soil Erodibility Nomograph for Farmland and Construction Sites," Journal of Soil and Water Conservation, **26**(5):189-192 (1971).

Wischmeier, W.H., and D. D. Smith, "Rainfall Energy and Its Relationship to Soil Loss," American Geophysical Union Agricultural, Transactions, 39(2):285-291 (1958).

Wischmeier, W.H., and D. D. Smith, "Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains," Agricultural Handbook No. 282, U.S. Government Printing Office, Washington, D.C. (1965).

Wischmeier, W. H., D. D. Smith, and R. E. Uhland, "Evaluation of Factors in the Soil-Loss Equation," Agricultural Engineer, 39(8):458 (1958).

Wolman, M. G., "Problems Posed by Sediment Derived from Construction Activities in Maryland," Report to the Maryland Water Pollution Control Commission, Annapolis, Maryland, 125 pages (1964).

Wolman, M. G., and A. P. Schick, "Effects of Construction of Fluvial Sediment, Urban, and Suburban Areas of Maryland," Water Resources Research, 3(2), 2nd Quarter (1967).

Yorke, T. H., and W.J. Davis, "Effects of Urbanization on Sediment Transport in Bel Pre Creek Basin, Maryland," U.S. Geological Survey Professional Paper 750-B, pp. 218-223 (1971).

Young, R. A., and C. K. Mutchler, "Effect of Slope Shape on Erosion and Runoff," Transactions, American Society of Agricultural Engineers, pp. 231-233 (1969).

IV. DOCUMENTED EXAMPLES OF SUCCESSFUL PROCEDURES FOR ESTABLISHING VEGETATION

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IV. DOCUMENTED EXAMPLES OF SUCCESSFUL PROCEDURES FOR ESTABLISHING VEGETATION

A. Introduction

Soils may be difficult to vegetate for several reasons. Some are too dry, too cold, too low in available nutrients, or too acid, and therefore, too high in soluble toxic aluminum. A soil or geologic parent material may also be difficult to vegetate because the slopes are too steep and surface creep and small landslides limit successful vegetation establishment. Slopes steeper than 2:1 (27 degrees, 50%) are usually in this category unless they are modified by breaking the continuity of the slope. They may also be very unproductive because they face south or west and are drier than slopes with a more favorable aspect.

The 10 demonstration sites documented in this section were selected because they represent an extensive area of soils and geologic parent materials of low productivity in the respective regions. Some of the sites are not productive because of low availability, water, temperature, fertility, or because of strong acidity (Table 5).

The Haplargids (arid soils) on the Lordsburg Bypass in southwestern New Mexico are not productive principally because of a deficiency of annual rainfall, which is slightly less than 25 cm (10 in.) and also because of a high rate of evaporation. By contrast, however, the Cryaquepts (cold soils) along the Alaskan pipeline also receive approximately 25 cm (10 in.) of annual precipitation, but water is not a limiting factor for establishing vegetation--cold weather limits plant establishment. The explanation is that on the New Mexico soils, the evaporation from an open water surface is 234 cm (92 in.)--9.4 times the annual precipitation. The area is classified as arid. By contrast, in Alaska, low temperatures and high humidity reduce the rate of evaporation to 56 cm (22 in.), 2.2 times the annual precipitation, and the area is classified as humid.

Temperature is a limiting factor in establishing vegetation on five of the 10 sites--Alaska, California, Colorado, Idaho, and Massachusetts. The northern latitude is the principal reason for low temperatures in Alaska; in Idaho and Massachusetts it is both latitude and altitude; and in California and Colorado, the reason for coldness is primarily due to the high altitude.

TABLE 5

ECOLOGICAL FACTORS LIMITING RAPID ESTABLISHMENT OF VEGETATION ON THE 10 DEMONSTRATION SITES

State/Great Soil Group	Available Water		Temperature		Fertility		Acidity	
Geologic Formation	Low	Adequate	Low	Adequate	Low	Adequate	Strong	Adequate
1. California								
Cryumbrepts (cold)		X	X		X			X
2. Idaho								
Xeropsamments (dry, sandy)		X	X		X			X
Xerorthents (dry)		X	X		X			X
3. New Mexico								
Haplargids (dry)	X			X		X		X
4. Colorado								
Cryorthents (cold)		X	X		X			X
5. Texas								
Weches Formation		X		X	X		X	
6. Mississippi								
Paleudults (old)		X		X	X		X	
Fragiudalfs (compacted)		X		X	X		X	
7. West Virginia								
Drystrochrepts (infertile)		X		X	X		*	*
Hapludults (least fertile)		X		X	X		*	*
8. Virginia								
Hapludults (least fertile)		X		X	X		X	
9. Massachusetts								
Haplorthods		X	X		X		X	
10. Alaska								
Cryaquepts (cold)		X	X			X		X

---

* Soils and geologic materials were both acid and alkaline.

Only two sites have soils that can be considered relatively fertile--Alaska and New Mexico. This does not mean, however, that plants here do not respond to chemical fertilizers. In Alaska the coldness reduces relative availability of nutrients, and in New Mexico the dryness reduces their relative availability over several months a year.

Strong acidity is a principal limiting factor in the rapid establishment of vegetation on Haplorthods in Massachusetts, Paleudults (old) and Fraguidalfs (compacted) in Mississippi, the Weches Formation in Texas, the Hapludults in Virginia, and on some of the soils in West Virginia.

Successful practices to establish vegetation that are documented in the 10 demonstration sites will be compared and contrasted.

All sites require some organic mulch to be applied after seeding or planting. On most sites grain straw is recommended, but in New Mexico, wild, long-stemmed, grass hay is preferred over straw because it has solid stems and therefore does not blow away so readily. In addition, wild hay contains many seeds of native plants that help to stabilize the soil. In Mississippi, pine needles are as good as, or better than, grain straw. Woodchips are preferred over straw in Massachusetts because of their stability and ready availability. All of these organic mulches, however, require about 25 lb of additional nitrogen (N) fertilizer per ton to compensate for bacterial tie-up during decomposition.

Topsoiling is desirable on all construction sites under these conditions:

1. When there is at least a foot of natural topsoil available to scrape off, store, and replace when the final grade has been achieved.

2. When the subsoil and geologic substratum are infertile, stony, sandy, or fine clayey, and the topsoil is suitable for plant growth.

3. When wild seeds and viable roots in the topsoil are needed to assure a rapid establishment of any kind of vegetation until the newly seeded species become established.

The choice of species of seeds or plants to be used is always a difficult problem. The more harsh the site environment the more necessary it is to select local, native species. The reason is that local species are adapted, while exotic species may not be. Seed should be produced under ecological conditions as similar as possible to the construction site where it will be used. Sometimes exotic species are recommended, but caution must be used as they may not be adaptable. There are governmental agencies who are continuously evaluating species under nearly every conceivable ecological condition. The decision maker must understand the differences between cool season and warm season grasses and legumes; between annuals and biennials for temporary seeding, and perennials for permanent seeding; between herbaceous plants and woody shrubs; as well as the relative compatibility of plants in mixtures.

The use of fertilizers is necessary on all 10 demonstration sites to assure rapid seeding establishment. Nitrogen is needed on all sites; and in Mississippi in areas with less than 60 in. of annual precipitation, and soils that leach readily, annual applications are recommended. Phosphorus needs can be approximated on each site only from a soil nutrient test. Potassium needs are usually less than for phosphorus, but again the amounts applied should be based on a soil test. The same is true for lime. Although soil pH is an indirect measure of lime requirement, a lime test based on replaceable hydrogen (the buffer test) is much more accurate. Lime and fertilizers should never be mixed before applying because of loss of nitrogen as ammonia. Neither should seed be mixed with fertilizer or lime because of injury to the seedlings.

B. Documented Examples

Following in sequence are the documented examples of successful procedures for establishing vegetation on soils that have been disturbed by construction activities on specific areas and sites in the States of California, Idaho, New Mexico, Colorado, Texas, Mississippi, West Virginia, Virginia, Massachusetts, and Alaska.

CALIFORNIA

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CALIFORNIA--DEMONSTRATION AREA NUMBER 1

HIGHWAY SLOPES IN THE LUTHER PASS AREA OF LAKE TAHOE

Summary

A cut slope on a highway near Lake Tahoe on Luther Pass* in the Sierra Nevada Range of central eastern California has been successfully vegetated, and the technology is documented here. Annual precipitation is 79 cm (31 in.), 55% of which is received during the three winter months. The Meeks very stony loamy coarse sand is the dominant soil in this glaciated area. It is noncohesive and does not have a large available water-holding capacity, estimated at 4.44 cm (1.75 in.) in the root zone. The Meeks soil series belongs to the Great Group of Cryumbrepts. This series is readily eroded and must be temporarily stabilized mechanically at the angle of repose before vegetation can be established. The slope on Luther Pass was planted with bundles of willow branches (wattles) lain horizontally on the contour in May 1973, and overseeded, by hydroseeding, with a mixture of adapted perennial grasses.

By the fall of 1974, the vegetation had successfully stabilized the slope. Nitrogen, phosphorus, and sulfur fertilizers are all essential for rapid establishment of vegetation in this area. Soil testing was not used on Luther Pass to determine fertilizer needs, but it should be recommended.

Essentially all the rainfall and snowmelt moves into the porous soil and moves laterally as subsurface flow. This water reappears on the surface on cut slopes along roadways, especially at the toe or ditch line. Such seepage causes unstable grades that often creep and slough, causing erosion and sediment. In local areas, shallow granite bedrock guides and directs the subsurface flow. Excessive wetness on the slopes is conducive to plant injury by frost heaving. Research is continuing on grasses, shrubs, and trees to more effectively stabilize the slopes.

---

* The Luther Pass Site has been extensively studied. This section has drawn freely from these studies, including results not yet published, of a recent study conducted by the California Department of Transportation (CALTRAN) with support from the Federal Highway Administration (CALTRAN Contract No. R.T.A. 13945-191210). Access to the results of this study are gratefully acknowledged. The conclusions and guidelines developed out of the Luther Pass study, and presented in this section are not official standards, specifications or regulations of California or the Federal Highway Administration.

I. INTRODUCTION

The Tahoe Basin (approximately 39 degrees north latitude, 120 degrees west longitude) is selected as typical of most of the revegetation problems of the Sierra Nevada Range of California. The soils have been recently studied and mapped.[1] Revegetation studies have been conducted by the University of California and the Soil Conservation Service, and highway erosion problems studied and defined by the California Department of Transportation.[2]

The specific demonstration site pictured here (Figures 19, 20, and 21) is a road cut (at least 20 years old) in the upper Truckee River watershed near Luther Pass on Highway 89 south of Lake Tahoe at an elevation of 2,316 m (7,600 ft). The road cut, about 30 m (100 ft) high by 122 m (400 ft) long, comprising about 0.4 ha (1 acre), is located at Post Mile 2.36 to 2.52. This southeast-facing cut has a slope angle of 34 degrees (1-1/2:1, 67 degrees) and prior to 1971 eroded at the rate of 83 m^3 (108 yd^3) per year,[3] or 136 mt (150 tons).[4] Total sediment discharge at the gaging station in this portion if the Truckee River basin was 313 mt (344.2 tons) March to June 1971), of which 157 mt (173 tons), or 50%, could be attributed to runoff from highways. About 90% of the annual suspended sediment discharge normally occurs during March through June at the time of the rapid snowmelt runoff when the subsurface of the soil is frozen. Selected chemical slope treatments for temporary erosion control in a freeze-thaw environment were evaluated on this slope from September 1971 to September 1972.

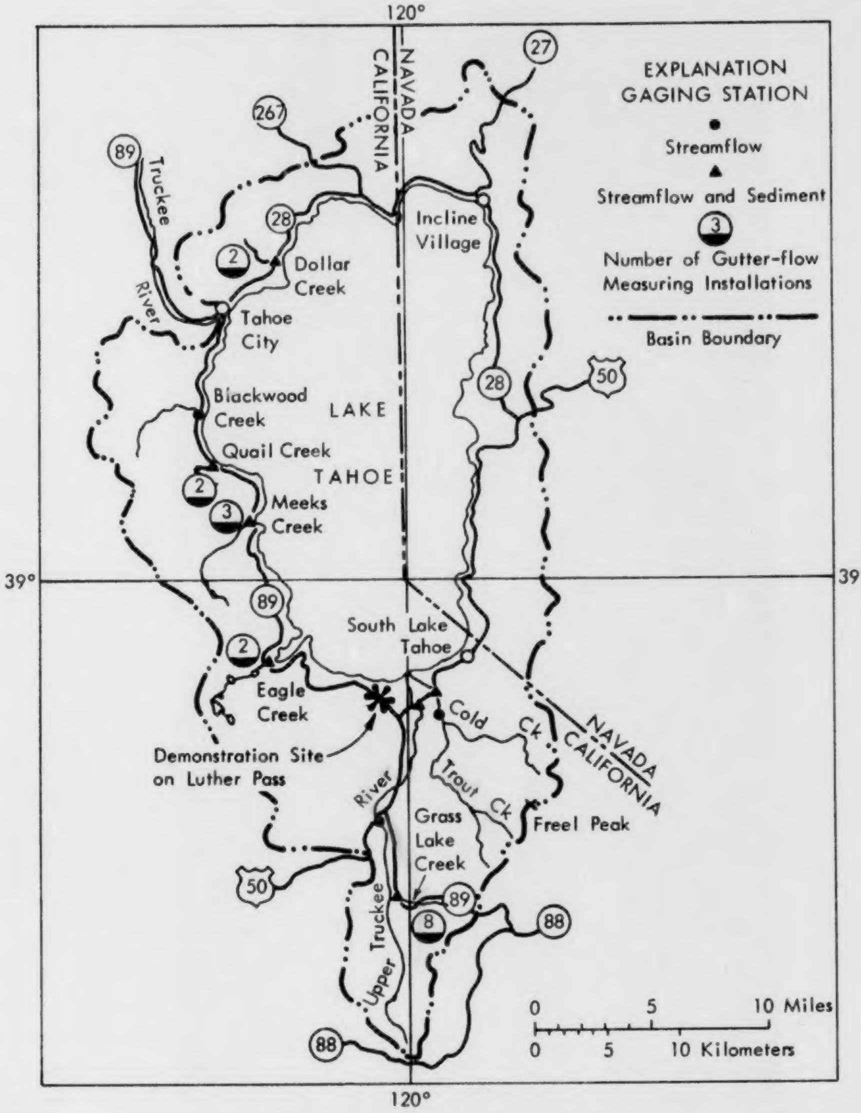
---

[1] Rogers, J. H., et al., "Soil Survey, Tahoe Basin Area, California and Nevada," Soil Conservation Service, USDA, 84 pages (1974.)

[2] Tahoe Planning Agency and Forest Service, USDA, South Lake Tahoe, California (1971). A series of publications: (1) "Climate and Quality of the Lake Tahoe Region," 31 pages. (2) "Hydrology and Water Resources of the Lake Tahoe Region," 22 pages. (3) "Soils of the Lake Tahoe Region," 21 pages. (4) "Vegetation of the Lake Tahoe Region," 38 pages.

[3] Beaton, J. L., "Slope Erosion Transects, Lake Tahoe Basin," Materials and Research Department Research Report No. M&R 657078-1, California Department of Transportation, 31 pages (1971).

[4] Quint, M., R. B. Howell, E. C. Shirley, and J. B. Skog, "Evaluation of Erosion from Chemically Treated Slopes, Luther Pass, Lake Tahoe Basin," Materials and Research Department Report CA-HY-MR-70785-3-73-17 03-954101, 23 pages (1973).


120°
NAVADA
CALIFORNIA
EXPLANATION
GAGING STATION
Streamflow
Streamflow and Sediment
Number of Gutter-flow Measuring Installations
Basin Boundary
Truckee
River
Dollar Creek
Tahoe City
Incline Village
Blackwood Creek
Quail Creek
LAKE
TAHOE
Meeks Creek
39°
39°
South Lake Tahoe
Eagle Creek
Demonstration Site on Luther Pass
Cold Ck
Trout Ck
Freel Peak
NAVADA
CALIFORNIA
Grass Lake Creek
Upper Truckee
River
0 5 10 Miles
0 5 10 Kilometers
120°

Source: Kroll, Carl G., "Sediment Discharge in the Lake Tahoe Basin, California," U.S. Geological Survey (1973).

Figure 19 - Location of Streamflow and Sediment Stations in Lake Tahoe Basin

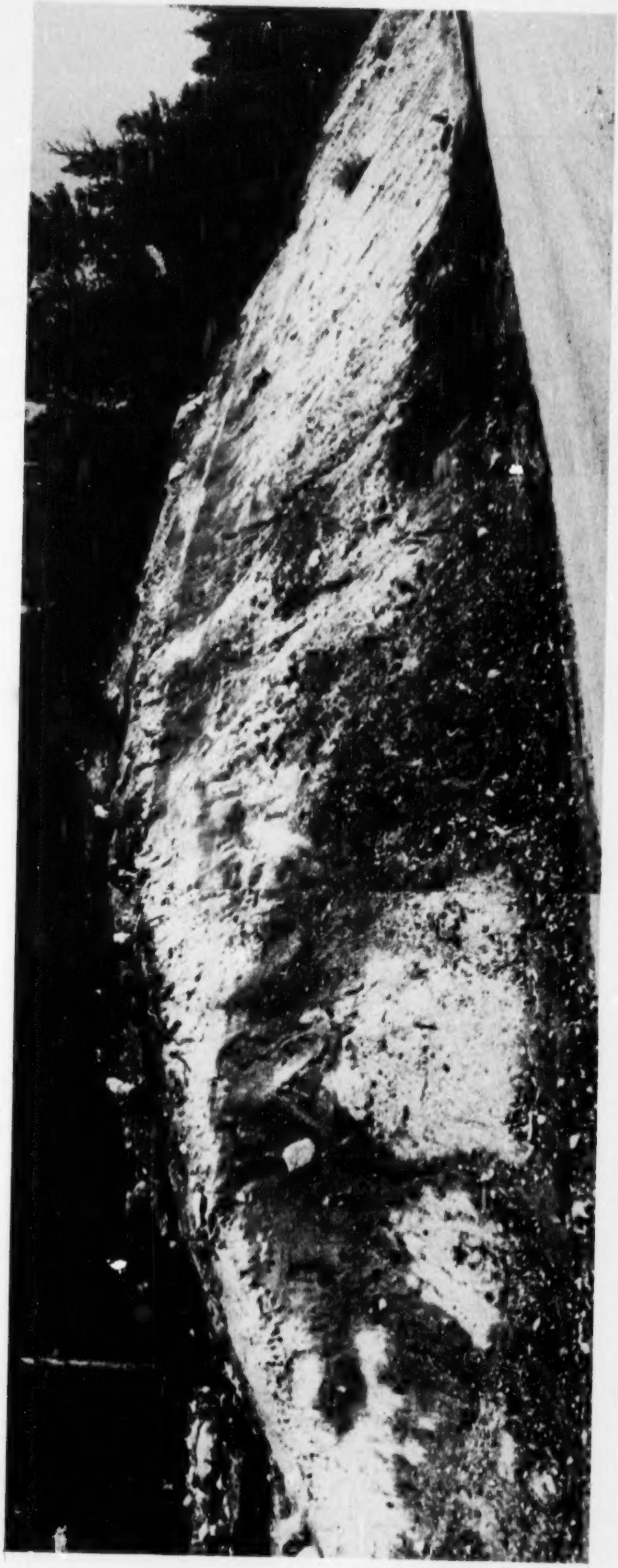
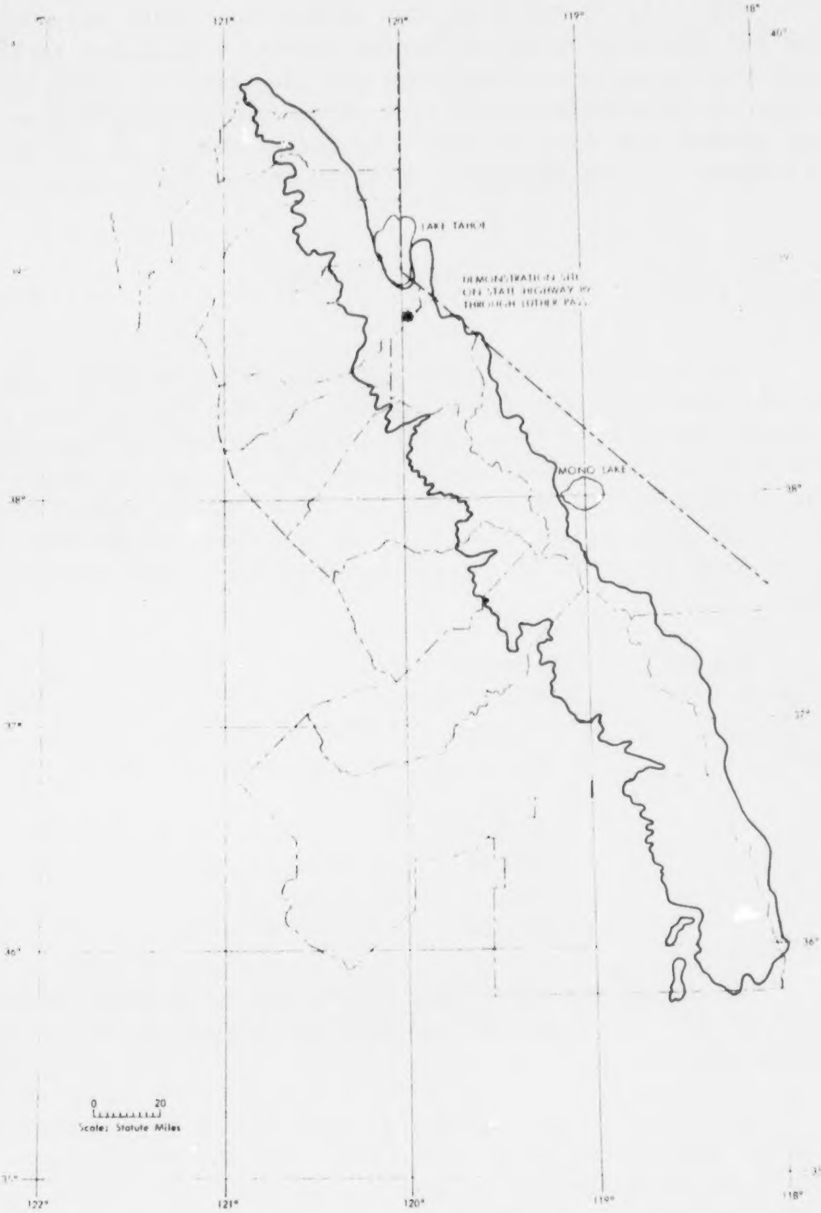


Figure 20 - The Demonstration Site on Luther Pass in the Sierra Nevada Mountains of California, Before Willow Wattles were Planted (Courtesy of California Division of Highways)


121°
120°
119°
118°
40°
LAKE TAHOE
DEMONSTRATION SITE
ON STATE HIGHWAY 89
THROUGH LUTHER PASS
MONO LAKE
38°
37°
36°
0 20
Scale: Statute Miles
35°
122°
121°
120°
119°
118°

Source: Huntington, G. L., University of California, Davis, Personal Communication to Francis William Bennett, Midwest Research Institute, 5 November 1974.

Figure 21 - The Demonstration Site in the Sierra Nevada Mountains of California and the Soil Great Group of Cryumbrepts to Which The Technology Applies

On 21 to 25 May 1973, the Luther Pass slope was contour-wattled and willow-planted, following promising research results the previous year on adjacent road cuts and elsewhere in the Tahoe Basin. The slope was then hydroseeded to a mixture of perennial grasses. Results through the fall of 1974 show this slope to be completely stabilized except for an occasional dislodgment of a few large rocks.

II. CLIMATE

The climate of the Sierra Nevada Range is influenced by the prevailing westerly winds during winter and the Pacific high pressure belt during summer, and is strongly influenced both by the elevation and the orientation of mountain ranges. Moist westerly winds from the Pacific Ocean move eastward across the Coast Range, across the Central Valley of California, and then over the Sierras. As the air masses rise on the western slope of the Sierra Nevada Range, high precipitation again occurs.

Annual precipitation on the western slopes of the Sierra Nevada Range is in excess of 125 cm (50 in.), and on the eastern slopes about 51 cm (20 in.). At Tahoe City, the nearest weather station, annual precipitation is 79 cm (31 in.), distributed by season as follows:

Spring - 18 cm (7 in.)
Summer - 2.5 cm (1 in.)
Fall - 15 cm (6 in.)
Winter - 43 cm (17 in.)

At elevations above Lake Tahoe, the precipitation increases to about 125 cm (50 in.), and the snowfall percentage of the total precipitation increases.

In 1 year in 20, the annual mean precipitation varies from about 60 to 150% of the mean. The number of days that receive 0.025 cm (0.01 in.) of precipitation or more varies from 40 at Tahoe City to about 60 at higher elevations.

At the demonstration site in Luther Pass, the annual precipitation is estimated between 89 and 102 cm (35 and 40 in.), received mostly as snowfall (Figure 22).

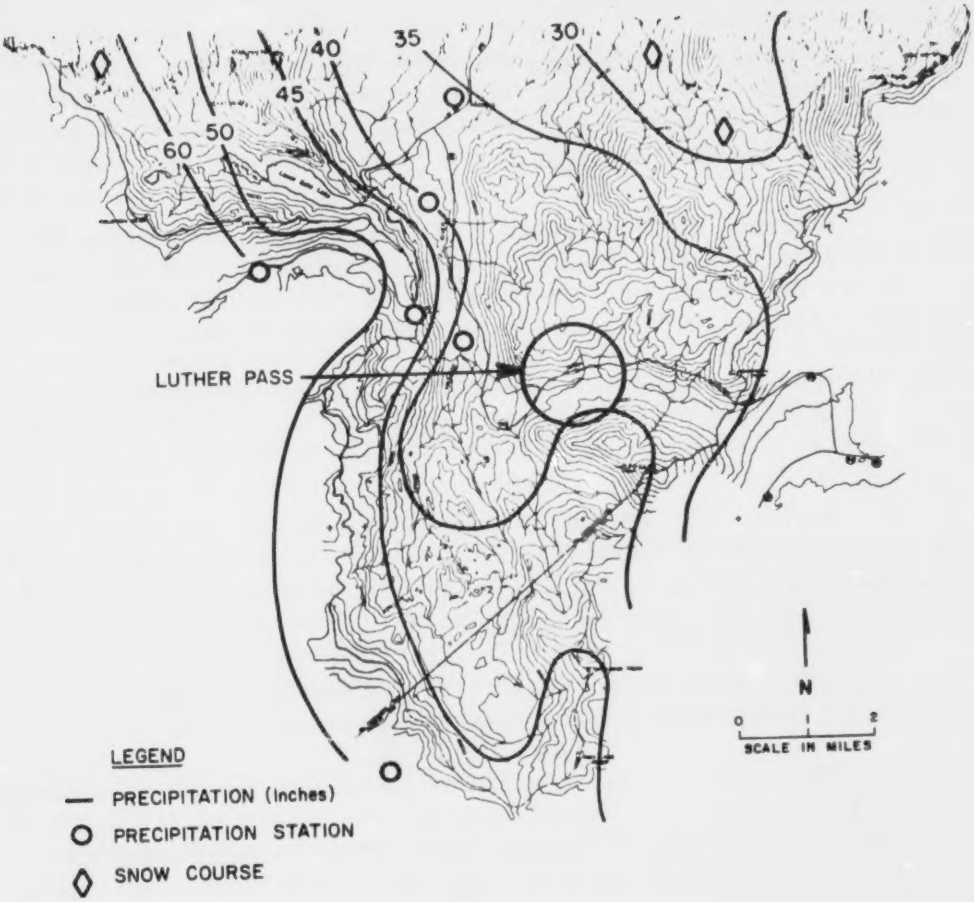

30
35
40
45
50
60
LUTHER PASS
N
0
1
2
SCALE IN MILES
LEGEND
PRECIPITATION (Inches)
PRECIPITATION STATION
SNOW COURSE

Figure 22 - Lake Tahoe Region, Showing the Topography, Mean Annual Precipitation, and Demonstration Site No. 1 on Luther Pass

Mean annual temperature at Tahoe City is 6°C (43°F), characterized by season as follows:

Spring - 4°C (39°F)
Summer - 14°C (58°F)
Fall - 7°C (45°F)
Winter - 2°C (28°F)

Extremes of temperature at Tahoe City are from about 35°C (95°F) to a low of -29°C (-20°F). Average monthly minima are from about 25°C (77°F) to 7°C (45°F). The extremes of temperature along the Luther Pass are predicted to be lower in both summer and winter.

III. SOIL

Soil at the road cut on the demonstration site along Luther Pass is classified as Meeks very stony loamy coarse sand in the family of sandy-skeletal, mixed, entic Cryumbrepts. The soil Great Group is Cryumbrepts and the order is Inceptisols.

In the soil survey report just referenced, pages 25 to 28, is the official description of the Meeks soil series:*

"The Meeks series consists of level to very steep, somewhat excessively drained, stony soils that are 104 to 178 cm (41 to 70 in.) deep over a hardpan weakly cemented with silica. These soils are on glacial outwash of Tioga and Tahoe age and on mountainous glacial moraines. (The demonstration site is on a lateral moraine with slopes of 30 to 60%.) The parent material is mixed but is dominantly of granitic origin. Slopes range from 0 to 60%. Elevations are 1,890 to 2,348 m (6,200 to 7,700 ft). Average annual precipitation is 89 to 114 cm (35 to 45 in.), average annual air temperature is about 3°C (41°F), and the frost-free season is 30 to 50 days. The vegetation is sparse coniferous woodland with an understory of brush and some perennial grass.

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* Soil Conservation Service, "Soil Survey, Tahoe Basin Area, California and Nevada," Soil Conservation Service and Forest Service, U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station, and University of Nevada Agricultural Experimental Station, March 1974, 84 pages and soil maps on a scale of 1:24,000.

"In a representative profile the surface layer is a grayish-brown and brown slightly acid very stony loamy coarse sand and gravelly loamy coarse sand about 29 cm (11 in.) thick. The next layers are pale brown slightly acid and medium acid gravelly loamy coarse sand and very gravelly loamy coarse sand about 127 cm (50 in.) thick. Below a depth of 155 cm (61 in.) is a light gray strongly acid gravelly loamy coarse sand that is weakly cemented with silica and has a nearly continuous very thin silica-cemented lamina on the surface.

"Permeability is rapid as far down as the weakly cemented substratum. It is slow in the substratum."

The Meeks soil series is further characterized as having rapid runoff, moderate natural erosion hazard, but a very high erosion hazard on sites disturbed by construction activities. The available water capacity in the average depth of root zone of 114 cm (45 in.) is about 4 cm (1-3/4 in.).

The Great Group of Cryumbrepts to which the Meeks series belongs and to which the vegetating technology applies comprises 1,936 km^2 (750.32 $miles^2$) in California and a grand total in the United States of 19,733 km^2 (7,650 $miles^2$), 0.22% of the total land area of the United States.

IV. THE PROBLEM

Lake Tahoe is famous for its deep blue color and clear water, typical of sterile alpine lakes. Any increase in fertility would promote eutrophication, with a resultant dullness of color, loss of clarity, and more plant growth. Sediment from man-caused soil disturbances in this basin are the greatest threat to this delicate balance. Construction of new State highways has been stopped mostly because of environmental concern, even though a need is suggested by traffic conditions. Therefore, a main concern is the progressive erosion on established highways, particularly on the cut slopes.

At the time the roads in the Lake Tahoe area were constructed, probably no seedings were made. But the native shrubs have established well, though slowly, on fill slopes. Even fill slopes on newly established roads in the basin are not a major source of sediment. By strong contrast, the cut slopes continue to be bare after 30 or more years and are still actively eroding. They are typically somewhat steeper than the natural angle of repose and have a concave face with an overhanging lip. The decomposed granite erodes at various rates throughout the year as a result of freezing and thawing, wetting and drying, wind, rainfall, and especially from waters flowing from snowmelt. The resulting accumulation of sediment in roadside ditches is removed by highway maintenance crews or is transported by rapid spring snowmelt into streams and into Lake Tahoe. Studies have documented the fact that sediment yield from cut slopes is highest in the spring during rapid snowmelt, and lowest during the winter when the soil is frozen and during the summer when the rainfall is the lowest and the soil is most permeable.

The problem of establishing vegetation either naturally or by artificial means is initial temporary mechanical stabilization of the slope. Erosion is so rapid that a seed cannot germinate and establish roots before being dislodged from the slope, even if germination is favored by adequate moisture and temperature conditions. A graphic example of the rapid erosion rate was noticed where gallon-size shrubs were transplanted onto a slope in late fall. By June, not only were the plants gone but there was no evidence of the 20 cm deep (8 in.) planting holes.

Other problems are caused by the inherent sterility and low water-holding capacity of the soil. The latter is particularly a problem to germinating seed. The decomposed granite will hold enough water for sparse plant growth once the roots are down but is seldom wet enough for a long enough period to permit satisfactory germination and seedling establishment. Fertility problems can be easily corrected by the addition of fertilizer. However, some environmentalists believe strongly that fertilizers should not be used because of the possibility that some nutrients will reach Lake Tahoe. The alternative is high sediment yield. Correctly used, according to a soil test, fertilizers will not pollute Lake Tahoe. Adapted exotic plant materials are generally available for use; however, local concern for using only native plant materials severely restricts this option and increases the cost.

Another consideration is that vegetation on the slopes blends with the natural forest or shrub-forest environment. Grass may contrast with an otherwise grassless vegetative type, particularly in mid-to-late summer, when the grass is dry. Dry grass is also undesirable because it is a fire hazard.

Limited success attended former efforts to stabilize the slopes by hydroseeding a slurry of grass and shrub seed plus fiber mulch and fertilizer. This technique usually resulted in a grass stand on only the lower one-third to one-half of the cut slope. The bare upper portion continued to erode, and debris accumulated in the grass of the lower portion until a slump occurred. Following maintenance, the slope returned to about the same condition as before seeding. Special practices are therefore needed to establish vegetation on the upper part of the slopes. The hydroseeding of tree and shrub seed was not successful, apparently because of poor germination condtions, with the seed on the surface and not coming in contact with moist soil, plus depredation by rodents and birds.

V. EVALUATION AND RECOMMENDATIONS

A. Introduction

Research on roadside cut slopes throughout the Basin was conducted by both the University of California and the Soil Conservation Service in 1969 through 1974, with early work researched.[1/] Efforts by the University included the use of native shrub materials combined with the use of grass for temporary erosion control during establishment of the shrubs, while the SCS has looked at the use of grass mixtures as well as shrubs--both native and introduced.

Propagation of native shrubs from seeds and cuttings was investigated by the University of California at Davis and by the SCS at their plant materials center at Lockeford, California. Nurseries of both grass and shrub materials were established at several locations in the Tahoe Basin. Soil fertility tests were conducted in the greenhouse at Davis. Mechanical and chemical stabilization techniques were researched in the literature, in test plots, and with local agencies. This information was then applied to existing road cuts, applying the research results to "watersheds" (culvert to culvert). The resulting sediment transport is observed by the U.S. Geological Survey.

Mechanical stabilization at the angle of repose is necessary if vegetation is to be established. The first consideration should be to keep surface drainage water from running over the slope by constructing a top-of-cut slope terrace. This terrace should be rock-lined or otherwise treated to prevent erosion. If necessary, energy-absorbing mechanisms should be used to reduce runoff velocity to nonerosive rates. This water should be discharged into a natural stream channel.

[1/] Kraebel, C. J., "Erosion Control on Mountain Roads," U.S. Department of Agriculture Circular No. 380, 45 pages (1936).

In all mechanical work, care should be taken not to disturb native vegetation. The equipment used must be the correct size for the job. Using equipment larger than needed causes problems such as increased compaction and unnecessary destruction of plant material. Hand work will often be the best method. For example, pack mules were used to haul rock to line the hand-constructed top-of-cut ditch above the watershed.

B. Breast Walls and Vegetation

Breast walls were installed on portions of two of the seven cuts on which complete revegetation was attempted. These breast walls reduced the effective height of the cuts and allowed a reduction in the grade of the slope. They have been perfectly stable through two winters. Because they were installed with considerable batter (back slope), soil materials were back-filled almost to the outer face of the breast walls; as a result, there does not seem to have been a problem with loosened rocks upslope catapulting onto the roadway. Although it was not done in this research, it is suggested that all interstices be filled with soil and with plant materials of a species such as native willow branches that will grow in these interstices. The technique is diagrammed in Figure 23.

C. Wattling

Wattling (bundles of woody "brush") partially buried in horizontal bands along the contour was used successfully in California in the 1930's to stabilize fill slopes and to assist in establishing other vegetation. It may never have been used to stabilize cut slopes. Wattling apparently was abandoned in the 1940's in this country, but it is still used in the European Alps as part of a highway revegetation program. Willow wattling was installed on several of the test sites at Luther Pass during the fall of 1972. In late May 1973, it was installed in a limited way on one cut on Highway 89 by personnel of the California Division of Highways. The recommended spacing of wattling for fill slopes is 1 m (3 to 4 ft); this spacing was used in research plots and in gullies.

Plant survival and erosion control by wattling was excellent after two growing seasons. The visual effect was good, and survival of both grasses and woody plants has been greatly enhanced by the wattling. Nearly all bundles of wattling rooted and remained alive throughout the summer. In addition, many of the willow stakes used to support the wattling rooted and grew. The practice of wattling has such a great potential for stabilizing soils and geologic parent materials of very low productivity that specification guidelines are given here.

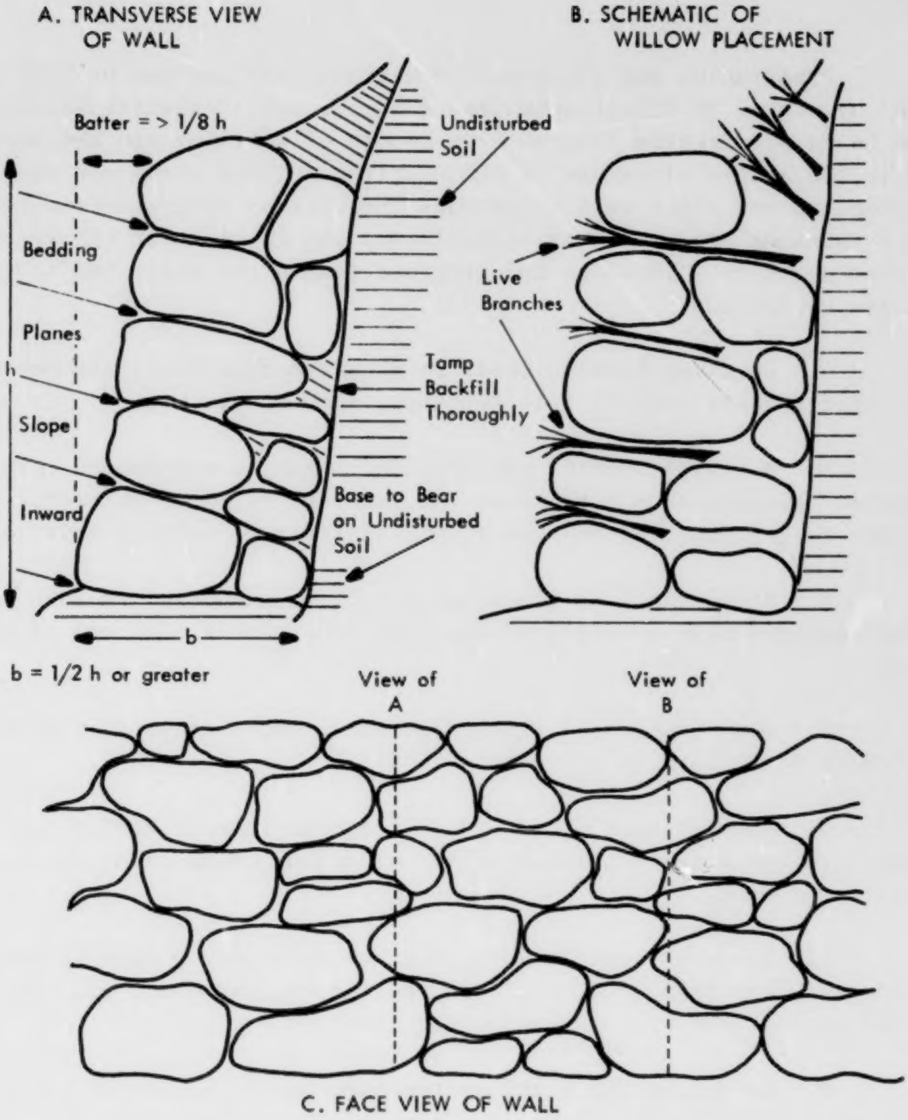

A. TRANSVERSE VIEW OF WALL
B. SCHEMATIC OF WILLOW PLACEMENT
Batter = > 1/8 h
Undisturbed Soil
Bedding
Planes
h
Slope
Inward
Tamp Backfill Thoroughly
Base to Bear on Undisturbed Soil
Live Branches
b
b = 1/2 h or greater
View of A
View of B
C. FACE VIEW OF WALL

Figure 23 - Breast Walls (rock rubble) Vegetation Stabilization. A and C: Construction detail showing bedding of rock on rock and general slope of stone into bank. B and C: Schematic detail of willow placement. After Leiser et al. study conducted for CALTRAN and sponsored by the Federal Highway Administration (1974a)

Preparation and placement of wattling can perhaps be best described by use of an illustration and a sample set of specifications. Figure 24 is a composite diagram of a bundle of wattling and the various steps in the proper placement of the wattling. These steps are shown as a progression and might well illustrate the various stages underway on a large wattling project. The installation should start at the bottom of either a cut or fill slope and progress toward the top. The specifications are as follows:

1. Wattling bundles shall be prepared from live, shrubby material that sprouts readily from cuttings, such as willow.

2. Wattling bundles may vary in length, depending on material available. Bundles should taper at the ends and be 30 to 46 cm (1 to 1-1/2 ft) longer than the average length of stems to achieve this taper.

3. Stems shall be placed alternately (randomly) in each bundle so that approximately one-half of the butt ends are at each end of the bundle.

4. When compressed firmly and tied, each bundle should be 20 to 25 cm (8 to 10 in.) in diameter.

5. Bundles should be tied on not more than 38 cm (15 in.) centers with two wraps of binder twine or heavier tying material, with a nonslipping knot.

6. Bundles should be prepared not more than 2 days in advance of placement, except that if kept covered and wet and cool, they may be prepared up to 7 days in advance of placement.

7. Grade for the wattling trenches should be staked with an Abney level, or similar device, and should follow slope contours (horizontal).

8. Trenches should be 1 m (3 ft) vertical spacing although economics may dictate wider placement.

9. Bundles should be laid in trenches dug to approximately one-half the diameter of the bundles, with ends of bundles overlapping at least 30 cm (12 in.). The overlap should be as long as necessary to permit staking as specified below.

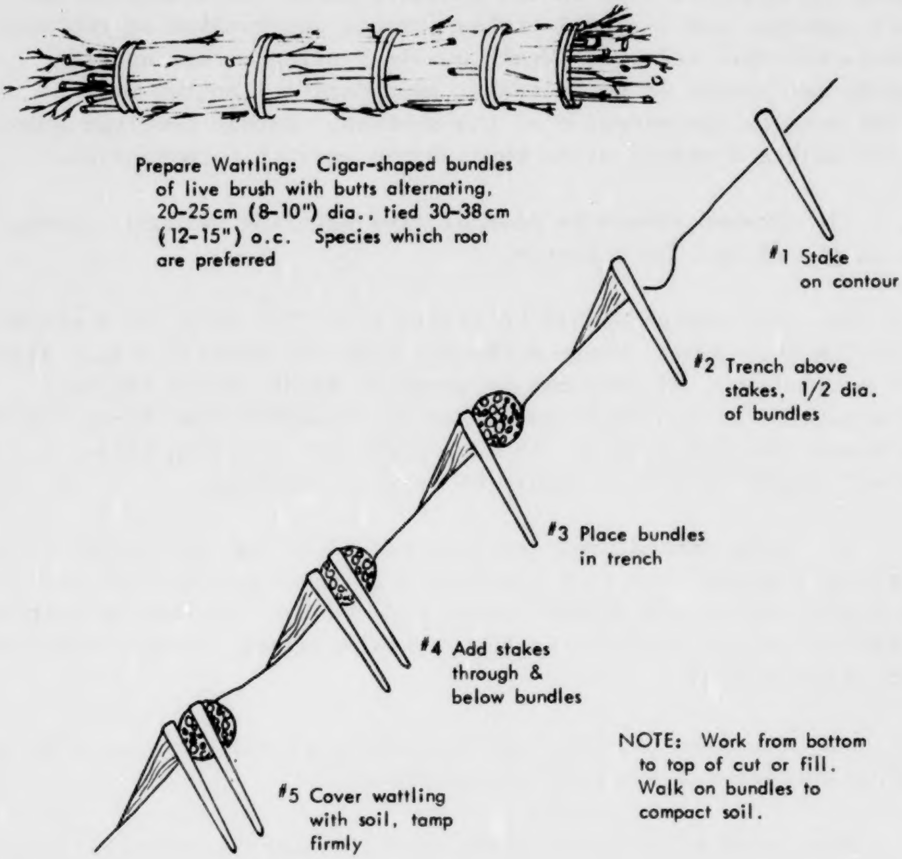

Prepare Wattling: Cigar-shaped bundles of live brush with butts alternating, 20-25cm (8-10") dia., tied 30-38cm (12-15") o.c. Species which root are preferred
#1 Stake on contour
#2 Trench above stakes, 1/2 dia. of bundles
#3 Place bundles in trench
#4 Add stakes through & below bundles
#5 Cover wattling with soil, tamp firmly
NOTE: Work from bottom to top of cut or fill. Walk on bundles to compact soil.

Figure 24 - Wattling Installation--Schematic Diagram Adapted from Leiser et al., 1974a. Study conducted for CALTRAN and sponsored by the Federal Highway Administration

10. Bundles should be staked firmly in place with vertical stakes on the downhill side of the wattling on not more than 46-cm (18-in.) centers, and diagonal stakes through the bundles on not more than 76-cm (30 in.) centers. Where bundle overlap occurs between previously set bottom or guidestakes, an additional bottom stake should be used at the midpoint of the overlap. Bundle overlaps should be "tied" with a diagonal stake through the ends of both bundles.

11. Stakes should be made of live wattling material greater than 4 cm (1-1/2 in.) in diameter.

12. All stakes should be driven to a firm hold and a minimum of 46 cm (18 in.) deep. Where soils are soft and 61-cm (24-in.) stakes are not solid (i.e., if they can be moved by hand), 91-cm (36-in.) stakes should be used. Where soils are so compacted that 61-cm (24-in.) stakes cannot be driven 46 cm (18 in.) deep, 10- to 13-mm (3/8- to 1/2-in.) steel reinforcing bars should be used for staking.

13. Work should progress from the bottom of the cut or fill slope toward the top, and each row should be covered with soil and packed firmly behind and on the uphill side of the wattling by tamping or by walking on the wattling as the work progresses, or by a combination of these methods.

14. The downhill "lip" of the wattling bundle may be left exposed when staking and covering are completed.

A wattled slope after plant establishment is shown in perspective in Figure 25.

D. Benching and Seeding

Benching (step construction) on very steep slopes is being used to some extent as a means of creating a medium for plant growth on the "tread" of each step and on the sloughed sediments at the base of each rise. If fertilized according to a soil nutrient test, seeded at the right season with the recommended plant species, and stabilized with an organic mulch, benched slopes can be quickly vegetated.

The decomposed granite in the Tahoe Basin is, however, usually not structurally suited to making stable benches. Benches on steep slopes (Figures 26 and 27), commonly in the Lake Tahoe area, often erode to a smooth slope approaching the natural angle of repose (about 1.5:1, 34 degrees, 67%).

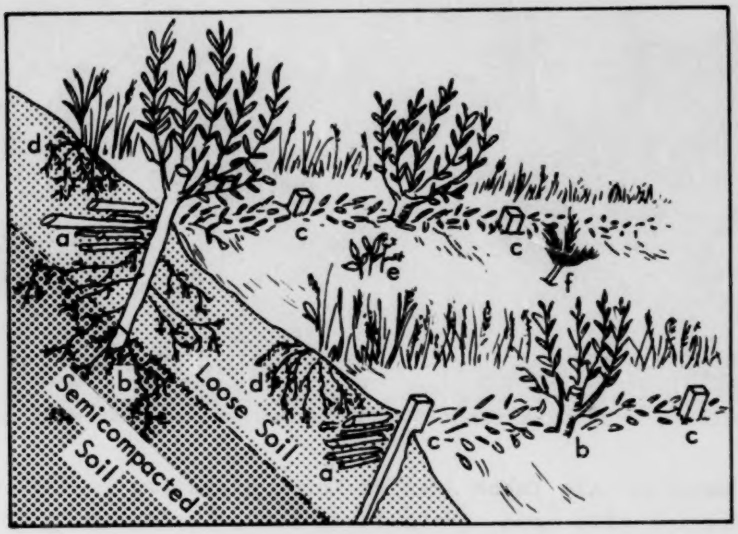


Figure 25 - Perspective of a Section of Treated Slope: a. Stems of cut brush "wattles" imbedded in contour trench, with portion of leaves and twigs protruding above slope surface, giving slight terrace effect; b. Stake of living willow or baccharis showing vigorous sprouts and good root system established--note that all stakes are set nearly at right angles to slope, not vertically; c. Inert stake of lumber or locally cut forest material, long enough to stand firmly in the semicompacted soil; d. Strip of cereal grain, 4 to 5 in. wide and 5 to 10 in. above the wattles, showing fibrous root systems--a temporary but rapid anchorage of the soil; e. Cluster of shrub or herb seedlings growing from a seed spot of permanent-cover species; f. Planted tree or shrub of permanent cover (Kraebel, 1936)

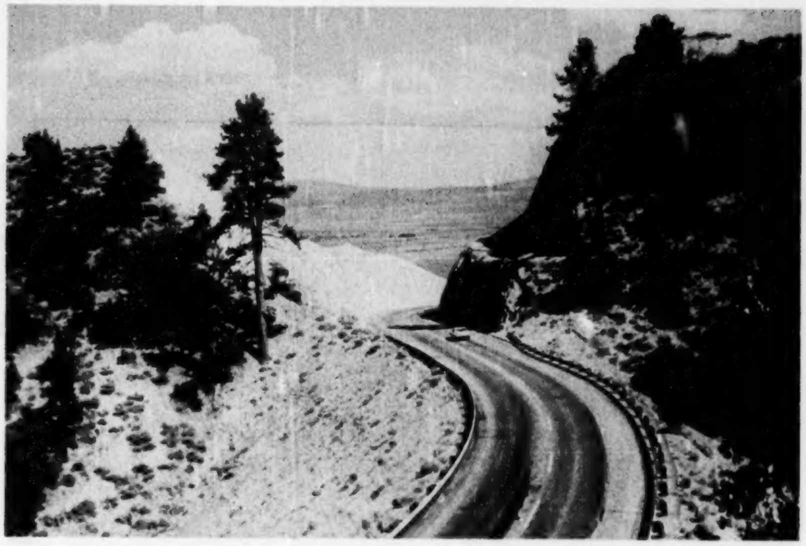


Figure 26 - General Lake Tahoe Area at Lower Elevation in the Luther Pass Demonstration Site Area. Note large benched slope on the right.

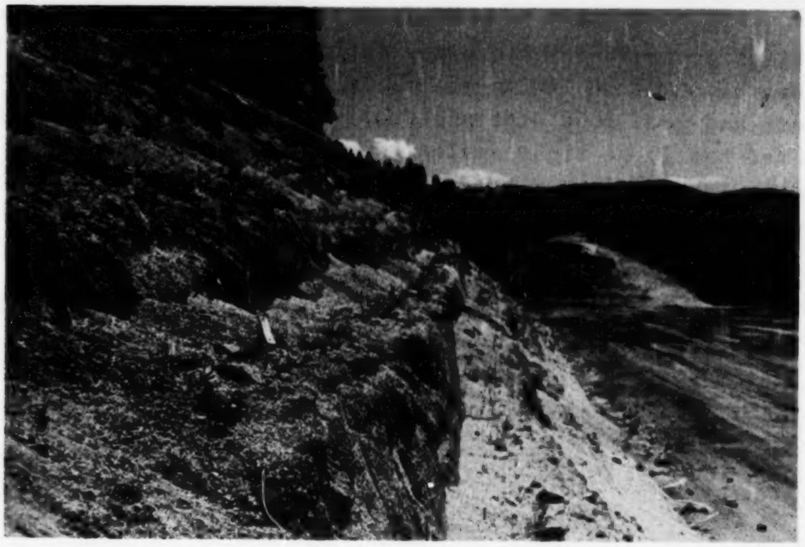


Figure 27 - Stair-Step Grading of Steep Slope. Note the sloughing at the Base of Each Rise (Courtesy of Burgess Kay).

E. Chemical Stabilization

A number of commercial chemical formulations are sold to reduce erosion when used alone on bare soil or in combination with plant materials. Some of these products have been field-tested in the Lake Tahoe area. Two of the polyvinyl acetate products were tested alone (without plants) for temporary erosion control near Luther Pass. It was observed that these materials reduced erosion.

A series of replicated plots at three locations in the Lake Tahoe area compared 12 stabilizing chemicals including a polyvinyl acetate in combination with seed and fertilizer. None of the chemicals were evaluated as any better than results from hydroseeding a slurry of seed, wood fiber, and fertilizer.

F. Fibers and Mats

Excelsior mats were included in the 1972 erosion-control chemical test and showed promise in early evaluations. Therefore, mats were tried again in the fall of 1972. Single and double thicknesses of a woven paper mat were compared with excelsior mats and wood fiber at 890 kg/ha (1,000 lb/acre). An average of the results at the two sites in July 1973 showed neither treatment to be an improvement over fiber alone. An evaluation in June 1974 showed hydroseeding to be superior to excelsior at one site but to be inferior at another. Excelsior is only slightly better than the single paper mat. Doubling the mat did not improve the results and may actually have reduced grass establishment.

Jute mats were not used in these tests but have been observed at many locations in the Tahoe Basin. Jute is more costly than excelsior and appears even more difficult to install properly. All mats are more expensive than hydromulching.

A major problem with mats is proper installation. They must be made to contact the soil uniformly. This is next to impossible on irregular surfaces such as gullies and over rocks. If not in complete contact, erosion will continue unchecked beneath the mat. A second problem noted was in tying mats securely to the slope. The 18 cm (7 in.) wire staples provided were ineffective on the rocky cuts. The mats were blown loose in some of the more exposed sites and were not effective.

Fibers tested include straw and wood fiber. Straw has been used successfully by placing a net over 1,120 to 4,480 kg/ha (1,000 to 4,000 lb/acre) of straw to prevent blowing. Surface-applied straw above 4,480 kg/ha (4,000 lb/acre) has been observed to smother the grass seedlings. A commercial chemical tested once to "tack" the straw (Terratack I) was ineffective. A new product (Terratack II), tested more recently, showed more promise. Asphalt is not used to tack straw in California because it is environmentally undesirable, inviting lawsuits when it inadvertently finds its way onto automobiles, people, and homes.

Wood fiber (virgin fiber, not reclaimed paper) has consistently shown its value in controlling erosion and improving grass stands. Increasing the rate above the minimal 1,120 kg/ha (1,000 lb/acre) to 2,240 kg/ha (2,000 lb/acre) or even 3,360 kg/ha (3,000 lb/acre) has increased its effectiveness. Field tests at Tahoe have consistently demonstrated the value of wood fiber at 1,120 kg/ha (1,000 lb/acre) to hold the seed in place, and increasing the rate has occasionally resulted in better stands of grass. Additional quantities have been observed to insulate the seedbed and delay germination.

None of the mulches appears to reduce problems of frost heaving. The only way to avoid the combination of temperature and moisture which causes heaving appears to be reseeding as often as is necessary.

Rice straw is preferred over wheat or barley straw because it does not contain grain or upland weed seeds, which may be competitive with seeded species and produce unsightly results particularly at lower elevations in the region.

G. Slope Surfaces

All surfaces, whether benched, wattled or sloped, should be left as rough as is practical, thus providing places for seeds to lodge and germinate. Most important, the seeds may become covered with soil, which is the best insurance for good results.

VI. SEED, SEEDING, PLANTING, AND RECOMMENDATIONS

A. Seedbed Preparation

Leaving a rough surface is the best practice. In experiments, covering the seed by drilling on gentle slopes or raking seed into a loose seedbed has consistently given the best results. Generally the most practical method of covering the seed is to apply it to a rough seedbed and allow the rains to cover the seed. The seed may be broadcast by hand or with a breast seeder. Covering by raking or dragging a chain over the surface is also good. If possible, on very coarse decomposed granite, cover the seed 0.5 to 1 cm (1/4 to 1/2 in.) deep or 2 cm (1 in.). Hard or crusted surfaces should first be scarified to improve the chances of covering the seed. On many sites the use of hydromulching may be the only logical method for applying the seed and fertilizer and is also a good method of applying mulch and fertilizer over previously covered seed.

B. When to Plant

Either late fall or early spring will give satisfactory results in some years. Use the following guidelines:

Fall seeding should be undertaken late enough that rains will not germinate the seed before snowfall. If germination occurs before snow, the seedlings may freeze. October is generally a good month. November is good if it is still possible to get on the area. It is best to have the job completed by early November, however, least snow catch the seeding half-finished. Fall seedings commonly germinate beneath the snow and can be seen growing as the snow melts in the spring.

Spring seedings are limited by the date of snowmelt. Many areas are inaccessible in spring because of wet conditions or late snow. If seeding is possible in March or April, however, it is often successful. May is generally too late, since there may not be enough rain to germinate the seed and allow the plants to reach a size which will survive the drying of the surface soil.

If irrigation is available, grass can be planted any time the site is accessible. The irrigation system should be designed so as not to wash away the seed. Once the grass is 15 to 20 cm (6 to 8 in.) high, irrigation can be discontinued.

C. What to Plant

A number of grasses are well adapted to such areas, and seed is available. They should be seeded at about 56 kg/ha (50 lb/acre) total. These can be grouped into bunch grasses and sod-forming grasses.

Bunch grasses are generally quick to establish and usually quite persistent. Most important are orchardgrass (a winter-hardy variety such as Potomac or Latar has given excellent results), Sherman big bluegrass, Nordan crested wheatgrass and fairway crested wheatgrass. To obtain quick ground cover, at least one of these should be included in all seedings. Durar hard fescuegrass is a very short fine bunch grass which should be seeded alone in special situations which demand a cover that is short and fine textured, but it would not be satisfactory where erosion protection must be maximum.

Sod-forming grasses are desirable because of their ability to spread. Establishment of herbaceous cover is often poor initially because of the difficult site conditions. In time, however, the rhizomes of this group of grasses will spread and improve the ground cover. Good sod-formers are Topar pubescent wheatgrass, Luna pubescent wheatgrass, Oahe, Greenar, and Amur intermediate wheatgrass, and Manchar smooth bromegrass. Luna pubescent wheatgrass has been the superior grass in SCS trials in the Tahoe Basin.

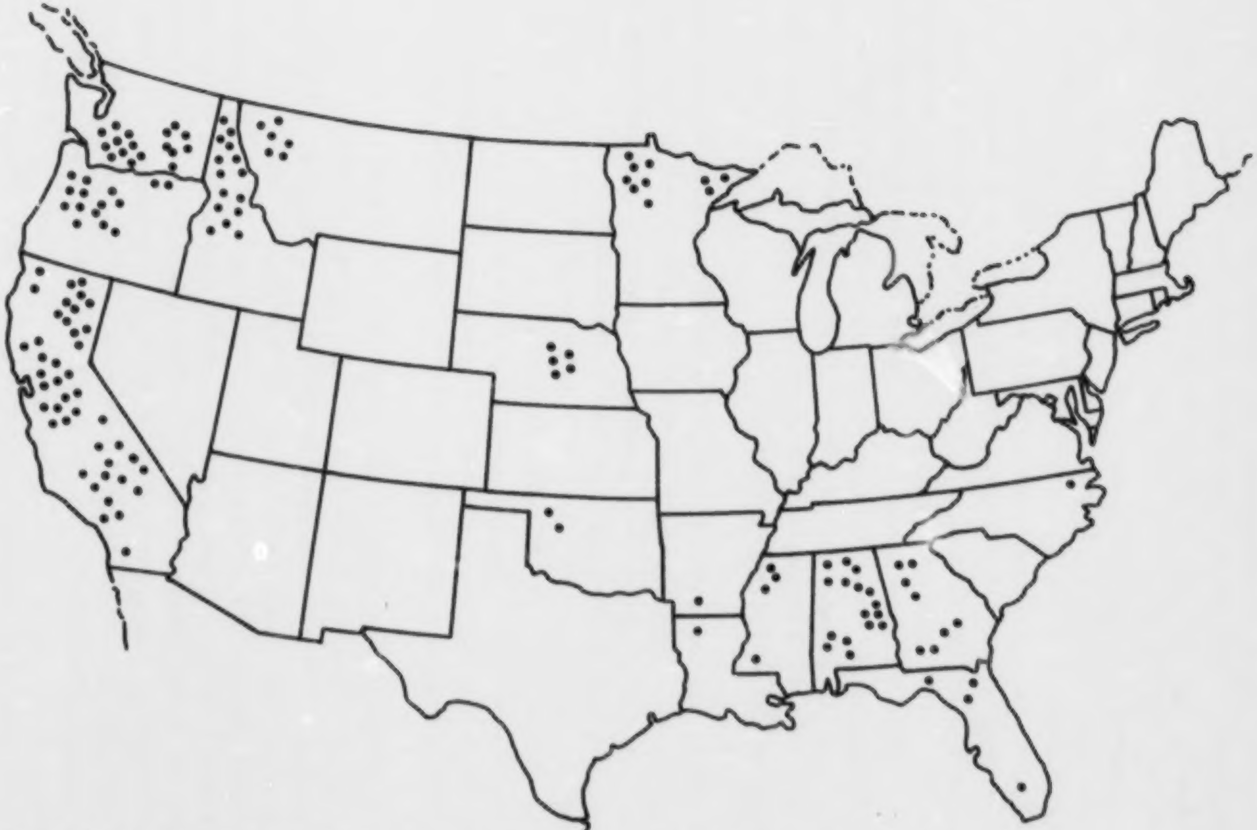
The desirability of including a legume because of its nitrogen-fixing potential is well recognized. However, most legumes have not done well at this location. Soil Conservation Service tests show promise for the legume, cicer milk vetch.

Temporary species, such as annual grasses or cereals, are not recommended. They often appear weedy, are a fire hazard, and do not give better protection than the fine-seeded bunch grasses listed on the preceding page. Also, they have been observed to crowd out the more desirable perennial grasses. The annuals then die, leaving a sparse ground cover.

Trees and shrubs are effective in long-term erosion control in the Lake Tahoe area. This conclusion should not be a surprise to ecologists since they are original vegetation. Trees and shrubs are also deeper-rooted than most grasses and are also capable of surviving at lower levels of fertility than the grasses. Grasses are needed for initial soil stabilization until the slower growing trees and shrubs become well established. Fertilizers are needed to hasten the establishment of grasses; and as the nutrients leach from the soil, the grasses gradually die and are replaced by native trees and shrubs. Shrubs which have potential are these native species: big sagebrush, penstemon, squawcarpet, pinemat manzanita, and bitter brush. Introduced species that have shown promise are Caucasian sagebrush and greenleaf manzanita; the latter is particularly suited to the drier sites. These native and introduced species are started in the greenhouse as seedlings or rooted cuttings and hardened out-of-doors before being transplanted at Lake Tahoe. Spring plantings (May) are much superior to fall plantings. Direct seeding of shrubs with fertilizer in individual holes was not successful. Trees do not seem to be well adapted to the shallow "soil" of cut slopes, although they may be used successfully on fill slopes for erosion control. Recommended as transplants for fill slopes are these tree species: Geffrey pine, lodgepole pine, incense cedar, and quaking aspen.

Pushing willow cuttings in soils on slopes have been a very successful practice. Again, the site must be stabilized at the angle of repose before the cuttings are planted. Larger willow cuttings have sprouted more profusely than smaller and younger branches. A comparison of cutting size, hormone treatment, and fall-versus-spring planting demonstrated the superiority of fall planting and of cuttings larger than 10 mm (3/8 in.) diameter. Second-year data show a marked decrease in the survival of fall-planted cuttings but an almost complete loss of the spring-planted cuttings. The hormone used did not increase the stand.

A specialized technique has been used to establish grass in the top portion of cut slopes, which is the most difficult area in which to establish plants. The erosion rate is generally too great to successfully establish plants from seed, so grasses are started in plant bands or peat pots in the greenhouse and transplanted to the road cut in the early spring. The germinating seedlings thus avoid the usual losses from frost heaving. Establishment has been better than 95%. The remainder of the slope can be hydroseeded when the transplanting is completed. Rhizomatous wheatgrasses are used (Topar and Luna pubescent wheatgrass, Sodar streambank wheatgrass and Barton western wheatgrass) in the hope that the creeping rhizomes will give maximum erosion protection. The use per hole of 1 g of nitrogen (a combination of available and slow-release forms) plus adequate phosphorus and sulfur are essential to plant establishment (Figure 28).



Source: Soil: The 1957 Yearbook of Agriculture, Washington, U.S. Department of Agriculture.

Figure 28 - Places Where Responses of Crops to Applied Sulfur Have Been Demonstrated by Field Experiments

Starting the grass plants requires about 18 days in the greenhouse, plus about 3 weeks outdoors at Davis, California, to harden before planting them at Lake Tahoe. They are started in flats of peat pots or plant bands in a sandy soil. The grass seed is sprinkled over the surface and covered lightly with soil. This results in a cluster of 5 to 20 grass plants in each band or pot.

VII. FERTILIZATION

Fertilizer is essential to the establishment and growth of grasses. The soils are deficient in nitrogen (N), phosphorus (P_2O_5), and sulfur (S). When N and P_2O_5 are applied as ammonium phosphate, there usually is sulfur (S) in the mixture. Blando (soft) bromegrass was grown on freshly eroded decomposed granite with a full complement of nutrients and compared with growth where each plant nutrient was deleted. Leaving out N, P_2O_5, or S, respectively, gave only 6, 16, and 12% of the yield of plants with complete nutrients (Table 6). A common mistake in this and other areas of California is to omit sulfur, supplying only N and P_2O_5. In this case only 12% of the potential of the fertilizer would be realized. Sulfur often adds little to the cost of fertilizer but in this case would increase its efficiency more than eightfold. Similarly, potassium (K) would be a waste of money since its omission actually resulted in higher yields, probably because of salt injury to seedlings. Because of the hazard of eutrophication of the waters of Lake Tahoe, rates of fertilizer application have been minimal. Minimum rates, however, have not been sufficient to induce a dense stand of protective grasses. In general, at least two applications of 280 kg/ha (250 lb/acre) of 16:20:0 plus sulfur are needed during the first year of seedling establishment, and one application at the beginning of the second growing season.

Research and demonstrations on the use of such slow-release fertilizers as Magamp (magnesium ammonium phosphate) have been conducted. Although the results are satisfactory, a cheaper alternative in the use of repeated applications of common rapid-release fertilizers.

Fertilization of shrubs other than penstemon has not been necessary, and sometimes is harmful. Fertilized penstemon, however, showed an increase in both survival and growth over those without fertilizer. Fertilization has decreased survival of some shrub species such as big sagebrush and bitterbrush.

TABLE 6

EFFECT OF NUTRIENT APPLICATION ON RELATIVE GROWTH OF BLANDO BROMEGRASS ON DECOMPOSED GRANITE[a]

Treatment	Relative Percent of Growth
All nutrients	100
+B	87
+Cu	104
+Mg	98
+Mn	64
-K	108
-N	6
-P	15
-S	12
-Zn	100
16:20:0	93
8:40:0	38

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a/ Martin, W. E., Department of Soils and Plant Nutrition, University of California at Davis (unpublished data).

Of the controlled-release fertilizers tested, only Agriform tablets, urea formaldehyde 20:10:5 (trade name Agriform), currently contain supplemental amounts of S. An appropriate addition of fertilizer for penstemon would be 1 to 2 g of nitrogen or approximately 1 to 2 tablespoons of most controlled-release fertilizers per plant.

Those who believe that fertilizer should not be used in the Tahoe Basin must recognize that grass will not grow without fertilizer and that the consequent erosion without grass will itself add nutrients as well as sediments to the lake. Fertilizer, properly used, is the lesser evil once the soil has been disturbed by construction.

VIII. FILL SLOPES IN NEW CONSTRUCTION

While fill slopes at a grade of 2:1 will generally vegetate naturally in time, it is desirable to speed the process. On a long-time basis, the costs incurred will usually be more than offset by reduced sedimentation, maintenance, and repairs.

Structures are essential to divert water from the fill slope or carry the water slowly over the slope without eroding.

The recommended surface treatment is to punch straw into the slope before seeding. Full-length straw (not chopped into short lengths) should be spread on the slope at 4,480 kg/ha (2 tons/acre) and punched in with a studded roller. Then an additional 4,480 kg (2 tons) should be used and the area rolled again. The finished product should resemble the tufts of a giant toothbrush. A recommended roller would be equipped with straight studs made of approximately 22 mm (7/8 in.) steel plates, placed approximately 20 cm (8 in.) apart and staggered. Studs should be not less than 15 cm (6 in.) long nor more than 15 cm (6 in.) wide and rounded to prevent withdrawing straw from soil. The roller should be of such weight as to shove the straw sufficiently into soil so as not to support combustion. A sheepsfoot tamping roller should not be used to incorporate straw into the slope material.

If the slope is difficult to penetrate, the straw should be applied to the surface at 2,240 to 4,480 kg/ha (2,000 to 4,000 lb/acre) and held in place with a net or wire.

Seeding and fertilizing should be done by broadcasting. Results have been good from seeding 60% of the seed and broadcasting all of the fertilizer between the two straw applications and the final 40% of the seed application on top of the second layer of straw. Broadcasting the seed may be with a breast seeder or in a hydroseeder. Fiber is not required except in centrifugal pumps, which may damage seed if used without fiber.

IX. SOURCES OF FURTHER RESOURCE INFORMATION

California Department of Transportation Laboratory
5900 Folsom Boulevard
Sacramento, California 95819

California Department of Transportation
Landscape Architects
1120 N Street
Sacramento, California 95814

Pacific Southwest Forest and Range Experiment Station
U.S. Forest Service
P.O. Box 245
Berkeley, California 94701

Soil Conservation Service
P.O. Box 68
Lockford, California 95237

University of California
Agricultural Extension Service
Davis, California 95616

University of California
Department of Agronomy and Range Science
Davis, California 95616

University of California
Department of Environmental Horticulture
Davis, California 95616

U.S. Forest Service
630 Sansome Street
San Francisco, California 94111

A list of commercial nurseries for sources of adapted seeds and plants may be obtained from the Resource Agency, Department of Conservation, Division of Forestry, Sacramento, California 95819.

X. ADDITIONAL REFERENCES

Carlson, J., "Propagation of High Elevation Shrubs," *Proceedings*, Erosion Control Symposium, 11 to 12 June, Sacramento, University of California at Davis, Agricultural Extension, pp. 67-74 (1974).

Edmundson, G., "Grasses and Legumes and Their Establishment for Erosion Control in the Tahoe Basin and Other High Elevation Sites in the Sierra Nevada Mountains," *Proceedings*, Erosion Control Symposium, 11 to 12 June, Sacramento, University of California at Davis, Agricultural Extension, pp. 75-81 (1974).

Howell, R. B., E. C. Shirley, and J. B. Skog, "Hydrology and Sediment Transport, Lake Tahoe Basin," Materials and Research Department Report No. 657078-2, California Department of Transportation (1971).

Howell, R. B., "Role of Mechanical Stabilization and Engineering in the Establishment of Plant Materials for Erosion Control," *Proceedings*, Erosion Control Symposium, 11 to 12 June, Sacramento, University of California at Davis, Agricultural Extension, pp. 20-22 (1974).

Kay, B. L, "Hydroseeding Limitations and Alternatives," Agronomy Progress Report No. 43, University of California at Davis, 3 pages (1972).

Kay, B. L., "Erosion Control Products Tested in the Tahoe Area," Agronomy Progress Report No. 48, University of California at Davis, 2 pages (1973A).

Kay, B. L., "Revegetation of Mountain Sites Above 3,000 Feet in California,": Agronomy Progress Report No. 53, University of California at Davis, 3 pages (1973B).

Kay, B. L., "Screening of Erosion Control Materials," Agronomy Progress Report No. 49, University of California at Davis, 6 pages (1973C).

Kay, B. L., "Wood Fiber Mulch Studies," Agronomy Progress Report No. 52, University of California at Davis, 6 pages (1973D).

Kay, B. L., "Erosion Control Products Tested on Decomposed Granite," Agronomy Progress Report No. 60, University of California at Davis, 7 pages (1974A).

Kay, B. L., "The Role of Erosion-Control Fibers and Chemicals," *Proceedings*, Erosion Control Symposium, 11 to 12 June, Sacramento, University of California at Davis, Agricultural Extention, 5 pages (1974C).

Kroll, C. G., "Sediment Discharge in the Lake Tahoe Basin, California," U.S. Geological Survey, 33 pages (1973).

Leiser, A. T., B. L. Kay, J. Paul, J. J. Nussbaum, and W. Thornhill, "Revegetation of Disturbed Soils in the Tahoe Region," Final Contract Report, California Department of Transportation R.T.A. 13945-191210 (1974A).

Leiser, A. T., and J. J. Nussbaum, "Wattling as an Erosion Control Method," Proceedings, Erosion Control Symposium, 11 to 12 June, Sacramento, University of California at Davis, Agricultural Extension, pp. 67-74 (1974B).

Nussbaum, J. J., and A. T. Leiser, "Shrub Establishment Methods," Proceedings, Erosion Control Symposium, 11 to 12 June, Sacramento, University of California at Davis, Agricultural Extension, pp. 67-74 (1974).

IDAHO

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IDAHO--DEMONSTRATION AREA NUMBER 2

FILL SLOPE, DEADWOOD ROAD IN THE IDAHO BATHOLITH

Summary

In the Boise National Forest in west central Idaho, a steep and long southwestern slope was successfully vegetated with ponderosa pine. The soils are Quartzburg and Toiyabe series, representative of the Idaho Batholith. Both soils are shallower than 76 cm (30 in.) and contain less than 10% silt plus clay. Under the shallow soils is weathered granitic bedrock. Annual precipitation is between 89 cm (35 in.) and 102 cm (40 in.), and almost all of it enters the soil and moves laterally as subsurface flow. The ponderosa pine seedlings were planted on the fill slope and 5 years later were successfully established. All attempts at establishing grasses were a failure. Fertilizer and straw mulch were considered essential for rapid establishment of the trees.

I. INTRODUCTION

The demonstration area selected for a detailed documented example of how to establish vegetation on disturbed soils in the Idaho Batholith is the 18 km (7 miles) Deadwood Road* (Figures 29 and 30). Road construction was stared in 1957, and construction was discontinued in 1970, after 18 km (7 miles) had been completed because of potential environmental impacts associated with additional construction in high erosion hazard areas. This decision was reinforced by the fact that failures on both cut and fill slopes on the existing road has supplied large volumes of sediment to the nearby Deadwood River.

The Idaho Batholith is a 41,400-km^2 (16,000-mile^2) area in central Idaho and western Montana, comprising igneous rocks, primarily granitic, mostly of quartz monzonite. The bedrock, when exposed,

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* The exact location of the Deadwood Road is Boise County, Township 9 north, Range 7 east, Sections 5, 8, 17, 20, and 29. The demonstration site is on a large fill slope in the southwest corner of section 8.

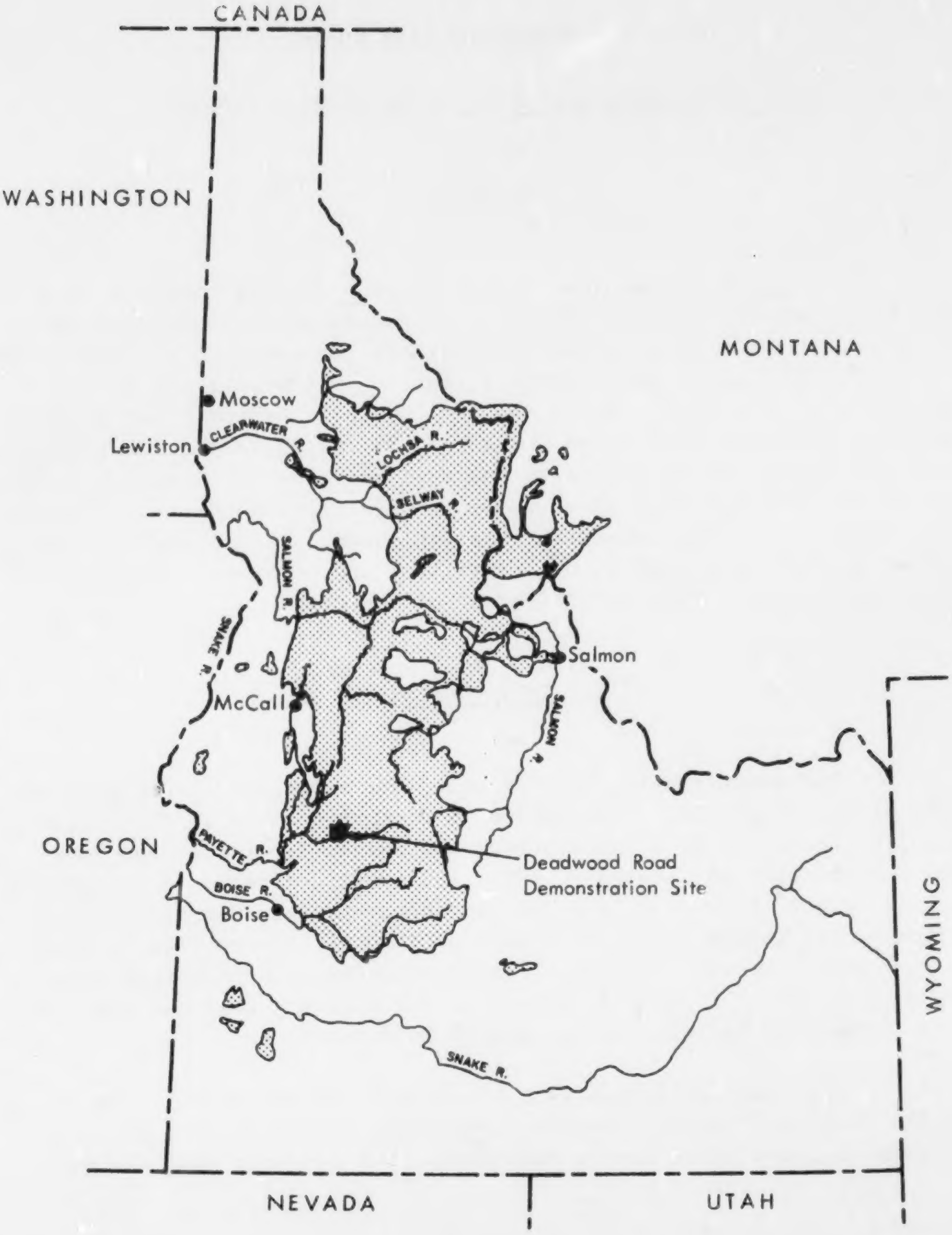
CANADA
WASHINGTON
MONTANA
Moscow
Lewiston
CLEARWATER R.
LOCHSA R.
SELWAY R.
SALMON R.
SNAKE R.
Salmon
McCall
SALMON R.
OREGON
PAYETTE R.
BOISE R.
Boise
Deadwood Road
Demonstration Site
WYOMING
SNAKE R.
NEVADA
UTAH

Figure 29 - The Idaho Batholith and the Deadwood Road Demonstration Site

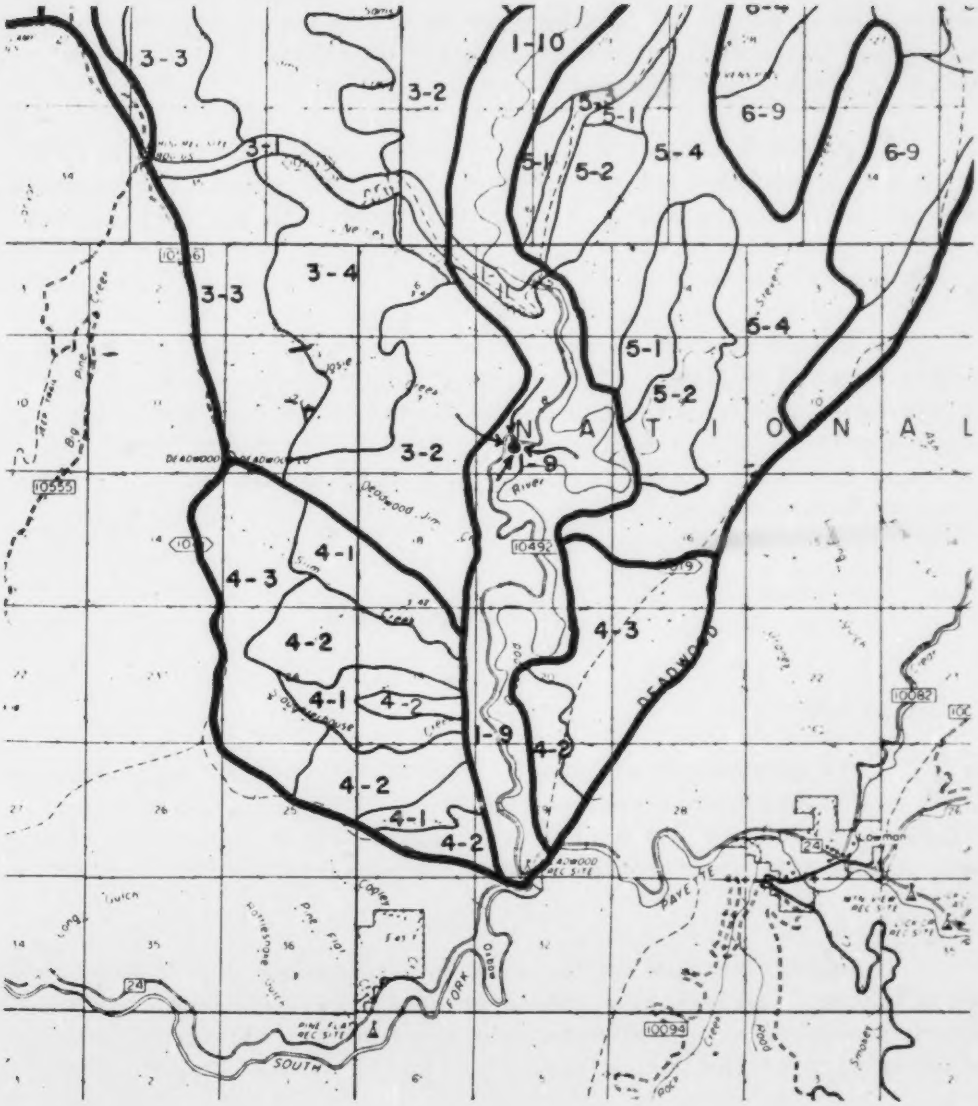
3-3
3-2
1-10
5-1
5-2
5-4
6-9
6-9
3-4
3-3
5-1
5-2
5-4
N A T I O N A L
3-2
1-9
4-1
4-3
4-2
4-1
4-2
4-3
1-9
4-2
4-2
4-1
4-2
DEADWOOD
River
PAYETTE
SOUTH
FORK
Lowman
24
24
10555
10492
10082
10094

Figure 30 - Location of Demonstration Site No. 2 on Deadwood Road (at arrows). The areas demarcated are land use divisions where timber harvesting and road building are restricted because of fragile soils.

weathers rapidly into coarse, loamy sand which is unstable on steep slopes because of a low percentage of clay to bind it. Overland flow resulting from rainstorms and rapid snowmelt can cause surface erosion; however, dry creep is an important erosion process on exposed soils. Mean annual precipitation ranges from 315 mm (15 in.) to 1,500 mm (60 in.), about 70% of which is snow.

Overland flow of runoff is minor. Most all of the precipitation moves into the streams as subsurface flow because infiltration rates in the soil are high. Road cuts intercept the subsurface flow of water and may cause slope failure. Such water cannot be intercepted by a diversion terrace, as is used on most soils of slow permeability.

The demonstration area is so fragile that the U.S. Forest Service in its Environmental Statement, Vol. 2,[1/] has declared that for the lower 7 miles of the Deadwood Canyon, only dead and dying timber should be harvested (area designated 1-9 in Figure 30). The statement further included this restriction on Area 1-10: "... Allow no timber harvesting activities..."

II. DEMONSTRATION SITE

A. Background

The demonstration site is on a 61 m (200 ft) long southwestern facing fill slope with a gradient of 70 to 75%. It is at an elevation of 1,410 m (4,700 ft), 90 m (300 ft) above Deadwood River. Soil materials in the fill area are from weathered granitic bedrock with a coarse texture.

Subsurface flow is the dominant phenomenon with regard to movement of water. Surface flow exists to some extent where the compacted road surface acts as a mini-watershed and supplies additional water to the upper part of the fill slope.

[1/] U.S. Forest Service Environmental Statement, Deadwood Planning Unit Land Use Plan, prepared in accordance with Section 102(2)(c) of Public Law 91-190, 29 March 1974. In two volumes, Vol. 1, 95 pages; Vol. 2, 89 pages.

The surface and subsurface materials before they were disturbed are classified and mapped as: Quartzburg series, a member of the sandy-skeletal, mixed, frigid family of Typic Xerorthents; or Toiyabe series, a member of the sandy, mixed, frigid shallow family of Typic Xeropsamments.

Both soil series are shallower than 76 cm (30 in.) and underlain by bedrock; both were formed in a temperature regime of 6 to 8°C (42 to 47°F) mean annual air temperature, and a mean summer soil temperature at a depth of 50 cm of 15 and 18°C (59 and 64°F). Both soil series are slightly acid throughout and contain < 25% silt and clay in the < 2-mm size fraction. The soil series differ primarily in the shallower-to-bedrock character of the Toiyabe which is 25 to 50 cm (10 to 20 in.); whereas, the Quartzburg series is 50 to 76 cm (20 to 30 in.) to bedrock. Both soil series are adequate in available potassium but low in nitrogen, phosphorus, and sulfur.

Deadwood Road was constructed in 1957, about 11 years prior to the establishment of the Forest Service research site. All extensive cut and fill slopes had previously been seeded with a grass mixture; in addition surface stabilization measures such as erosion control netting, asphalt-tacked straw, and other treatments had been applied on many of the areas.

The first and second attempts at establishing grasses at the study site failed because of (a) excessive erosion, especially during an 11-day storm in December 1964, (b) grazing destruction by deer and elk, and (c) distrubance of the slope during road maintenance operations.

The mechanical and ecological technology reported for this demonstration site is applicable to most of the 41,440-km^2 (16,000-mile^2) area of the Idaho Batholith, within these paramter restrictions:

1. South of the Salmon River (Figure 29, page 124);
    a. Elevations between 900 and 1,500 m (3,000 and 5,000 ft),

    b. Precipitation less than 1 m (40 in.),

    c. Southerly aspects,

    d. Areas within the range of ponderosa pine, and

    e. Dry, coarse-textured Entisols (Orthents or Psamments).

2. North of the Salmon River;

   a. Elevation below 1,219 m (4,000 ft),

   b. Precipitation less than 88.9 cm (35 in.),

   c. Southerly aspects,

   d. Areas within the range of ponderosa pine, and

   e. Dry, coarse-textured Entisols (Orthents or Psamments).

B. Vegetation Establishment

The demonstration site was essentially bare at the time of the establishment of the study plots.[1] Treatments were applied on the study plots in a randomized block design using 3 blocks of 10 plots each. Each plot was 2.18 x 9 m (7.25 x 30.0 ft) in size [total area of 0.008 ha (1,200 of an acre)] with the long axis oriented up and down the slope. Deflection boards were established on the upper side of each plot to reduce the hazard of rocks rolling across the plots. On the sides were 2.5 x 30 cm (1 x 12 in.) boards. A plastic-lined trough was built at the lower end of each plot to catch sediment for weighing. On some plots, straw mulch was applied to a depth of 2.5 to 5 cm (1 to 2 in.) and was held in place by galvanized poultry wire (Figure 31).

Ponderosa pine were planted on the site. Fertilizer applied consisted of one Treefeed pellet, analyzing 28% N, 5% P_2O_5, and no potassium. For trees spaced 45 x 45 cm (1.5 x 1.5 ft), the fertilizer application amounted to a rate per acre of 49 kg (109 lb) of N and 8.6 kg (19 lb) of P_2O_5; on the trees spaced 76 x 76 cm (2.5 x 2.5 ft), quantity was 18 kg (40 lb) of N and 3 kg (7 lb) of P_2O_5.

Ten treatments were applied as follows:

1. Control (no seed, no plants, no straw, no wire netting).

2. Seeds (grass), straw mulch, erosion net, fertilizer.

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[1] Megahan, W. F., "Deep-Rooted Plants for Erosion Control on Granitic Road Fills in the Idaho Batholith," Intermountain Forest and Range Experiment Station Research Paper INT 161, USDA Forest Service 22 pages (1974).

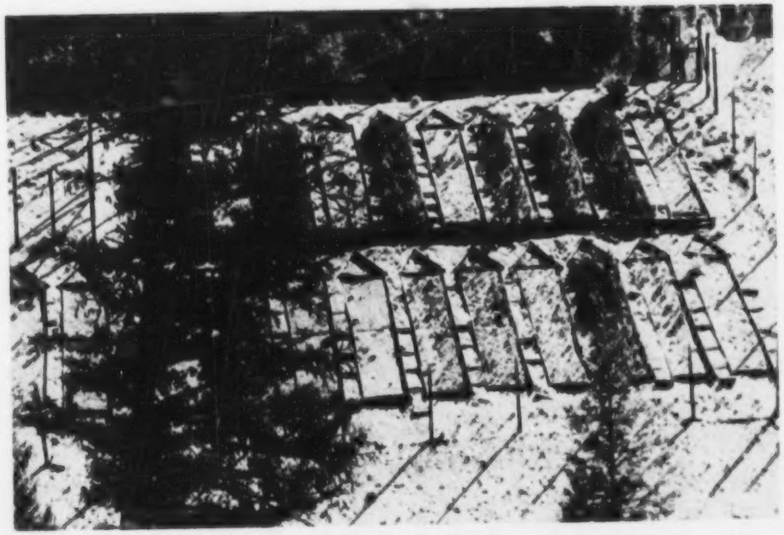

Figure 31 - The Research Site on Deadwood Road that is Used to Demonstrate the Most Feasible Method of Establishing Vegetation on Steep and Long Slopes of Low Productivity. The wood frames protect each plot from surface creep. (Courtesy USDA Forest Service)

3. Seeds (ponderosa pine), straw mulch, erosion net, fertilizer.

4. Seeds (ponderosa pine), straw mulch, erosion net.

5. Plants (ponderosa pine), 45 x 45 cm (1.5 x 1.5 ft) spacing, straw mulch, erosion net, fertilizer.

6. Plants (ponderosa pine), 45 x 45 cm (1.5 x 1.5 ft) spacing, straw mulch, erosion net.

7. Plants (ponderosa pine), 76 x 76 cm (2.5 x 2.5 ft) spacing, straw mulch, erosion net, fertilizer.

8. Plants (ponderosa pine), 76 x 76 cm (2.5 x 2.5 ft) spacing, straw mulch, erosion net.

9. Plants (ponderosa pine), 45 x 45 cm (1.5 x 1.5 ft) spacing.

10. Plants (ponderosa pine), 76 x 76 cm (2.5 x 2.5 ft) spacing.

The trees were 2-0 planting stock* from local seed sources. They were planted in April 1968, but many were damaged by deer and elk. All locations where trees had died were replanted a year later after an elk-proof fence had been constructed around all experimental plots. Tree and grass seeds were seeded in October 1968. The tree seeds were coated with rodent repellent and seeded at the rate of 275 seeds per plot (2.8 kg/ha) (2.5 lb/acre) by handplacing seed through the straw mulch. Grasses were seeded at the rate of 56 kg/ha (50 lb/acre) and consisted of equal weights of:

Pubescent wheatgrass;

Oatgrass;

Smooth bromegrass;

Crested wheatgrass; and

Intermediate wheatgrass.

The straw mulch was removed before seeding grass and immediately replaced.

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* 2-0 Planting stock means 2-year-old seedlings that had not been transplanted.

All growth data were collected for a 4-year period and erosion data for 3-1/2 years.

C. Plant Response

Plant density on the grass plots decreased from 17 plants/m^2 (1.5 plants/ft^2) to less than 0.09/m^2 (1/ft^2) over the 4-year period of the experiment. Decreases in grass density were common in the area; they may have been accentuated on these plots by invasions of grasshoppers in 1971 and 1972.

At the end of the 1st year, 12% of all ponderosa pine seeds had emerged; this percentage decreased to 5% at the end of 4 years; most of the surviving trees exhibited poor vigor. In 1969, there were 2,680 trees/ha (6,500 trees/acre). Survival of planted ponderosa pine trees, however, was excellent. Six of the 18 plots had 100% survival, and only two plots had less than 95% survival. On all 18 plots the survival averaged 97%.

In summary, fertilizer response of all plants was significant; mulching and increased spacing increased plant growth, but increases were not statistically significant in most instances.

D. Sediment and Its Control

In the Idaho Batholith in an undisturbed forest, background sediment yield was estimated at 8.8 mt/km^2/year (25 tons/$mile^2$/year). Disturbances such as cutting and skidding logs increases sediment yields by a factor of 1.6. Sediment runoff from forest roads undergoing construction increased by a factor of 220 (Table 7).

Nearly all accelerated sediment production from logging operations on forest lands in the Idaho Batholith resulted from logging road construction, and 84% of the sediment yield was produced during the 1st year.1/

1/ Megahan, W. F., and W. J. Kidd, "Effects of Logging on Sediment Production Rates in the Idaho Batholigh," USDA Forest Service, Research Paper INT-123, 14 pages (1972).

TABLE 7

SEDIMENT YIELDS COMPARED FROM FOREST ROADS, TIMBER HARVESTING AND FROM UNDISTURBED FOREST IN THE IDAHO BATHOLITH

(6-year mean[a])

Type of Forest Disturbance	Sediment Yield Per Year mt/km^2	Sediment Yield Per Year tons/mile^2	Ratio of Sediment Yield (disturbed/undisturbed)
Undisturbed	8.8	25	1.0
Cutting Plus Skidding Logs	14	40	1.6
Forest Road Construction	1,927	5,500	220.0

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[a] Megahan, W. F., "Logging, Erosion, Sediment--Are They Dirty Words?," *Journal of Forestry*, Vol. 7, No. 7, 5 pages, July 1972.

The effects of seeding a grass mixture on logging roadbeds in Idaho, after completion of logging and for the purpose of stabilizing the soil, has been studied.[1] The seeding mixture consisted of 40 kg/ha (36 lb/acre) of the following grass species (Table 8).

The mean density of grass species for 1957 and 1958 is shown in Table 9.[2]

---

[1] Kidd, W. J., Jr., and H. F. Haupt, "Effects of Seedbed Treatment on Grass Establishment on Logging Roadbeds in Central Idaho," USDA Forest Service, Research Paper INT-53, 9 pages (1968).

[2] Ibid.

TABLE 8

GRASS SEEDING MIXTURE AND SEEDING RATE

Species	Rate kg/ha	Rate lb/acre
Winter Ryegrass	22	20
Manchar Smooth Bromegrass	6	5
Intermediate Wheatgrass	6	5
Crested Wheatgrass	3	3
Bulbous Bluegrass	2	2
Timothy	1	1
Total	40	36

TABLE 9

SEEDING ESTABLISHMENT MEANS FOR GRASS SPECIES (1957 AND 1958)

Species	Mean Seedling Establishment plants/m^2	Mean Seedling Establishment plants/ft^2
Intermediate Plus Crested Wheatgrasses	0.3	3.8
Manchar Smooth Bromegrass	0.2	2.6
Timothy	0.1	1.5
Bulbous Bluegrass	0.6	0.7
Winter Ryegrass	0.4	0.4
Total	0.8	9.4

The number of grass plants established increased as the direction of slope changed from south to north. Ripping of the compacted roadbed was more favorable to seedling establishment than compacted areas. Mulching with woodchips and no fertilizer depressed grass seedling establishment.

Road cuts in the Idaho Batholith generate considerable overland flow by intercepting subsurface flow or groundwater. The reduced infiltration rates on compacted road surfaces provided more water; therefore, adequate drainage in the form of culverts and cross ditches is an absolute necessity. Surface water from road surfaces must not be allowed to flow upon highly erodible roadfill materials farther downslope. In most cases, this requires insloping road surfaces. Cut and fill slopes should be slopes at or less than the angle of stability for the specific soil materials before vegetation can be expected to stabilize them. Much of the erosion in the Idaho Batholith is caused by "dry and wet creep." "Dry creep" is assisted by high winds and gravity; "wet creep" is associated with raindrop splash, ice crystal formation (heaving), surface ice and snow freezing and thawing, and sliding due to gravity. "Dry and wet creep" erosion can be controlled best by plants producing a maximum amount of crown cover and litter for surface protection. Deep-rooted plants such as trees provide added benefit by helping reduce the likelihood for mass erosion (landslides).

Trees were used on the demonstration site on the Deadwood Road, and the results are reported here. Compared with the control plots, the surface erosion rate from plots where trees were planted was reduced by an average of 44%; mulched surfaces under trees reduced erosion by 95%. Because of decomposition of the mulch, the erosion control effectiveness of the mulched plots planted to trees decreased over the 3-year period from 98 to 92%, respectively (Figure 32). The ponderosa pine trees control erosion effectively by intercepting some rainfall, breaking the velocity of raindrops, providing a surface mulch of shed needles, and by binding the soil with tree roots.

III. ALTERNATIVE DECISIONS ON PLANT SELECTION

Since more than three-fourths of all sediment from construction activities in the Idaho Batholith is produced during the 1st year, mulching or some other surface treatment should be mandatory as soon as the final grades have been established to prevent this 1st year's sediment loss. Mulch will begin to decompose and will decrease in effectiveness as a sediment retardant after about 3 years. During this period, wild seedlings probably will not become dense enough to hold the soil; as a result, the only effective alternative is to establish perennial vegetation at the same time or soon after mulch is applied.

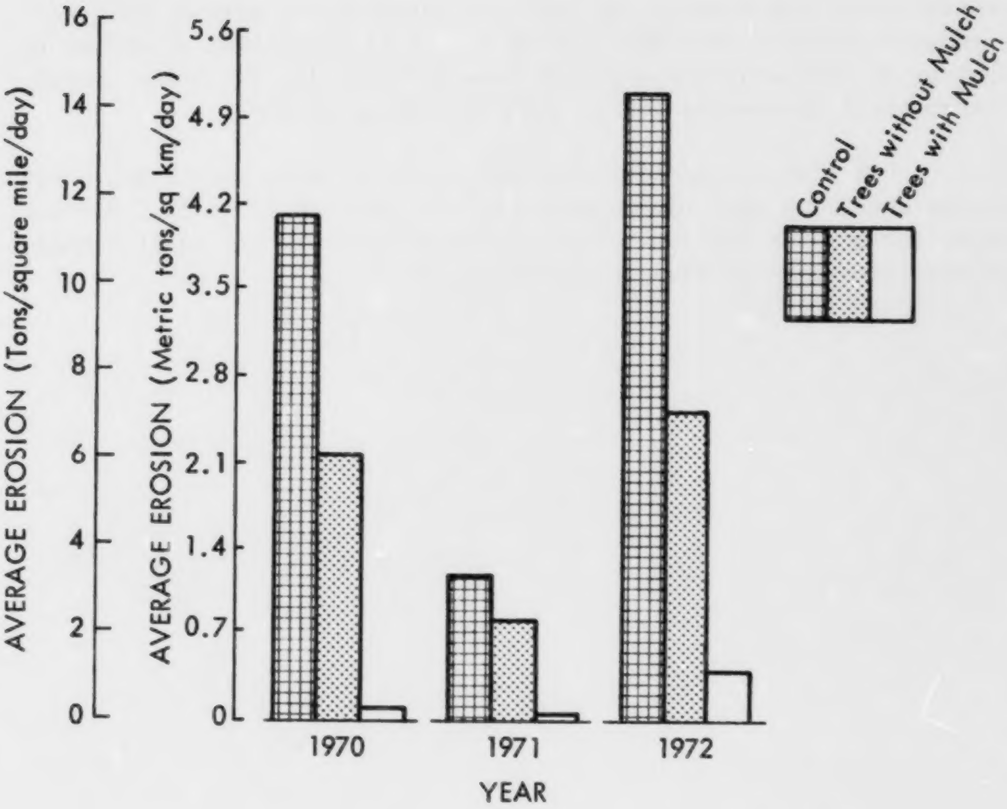

Figure 32 - On the Deadwood Demonstration Site, Mulched Trees Reduced Erosion by an Average of 95% Over Control Plot. Trees alone reduced erosion an average of 44%.

The list of adapted and available plant species is extensive, and decisions must be made as to alternative choices. Because of the prevalence of soil slumps, deep-rooted species should have preference over shallow-rooted ones. Trees and shrubs that have been grown at the nearby Lucky Peak Nursery and that are suitable for holding soil are portrayed in Table 10. The list of plants is classified according to ecological site adaption (habitat type series), dry (mountain brush), intermediate (ponderosa pine), and moist (Douglas fir).

A list for special uses (adapted companion seedlings, herbaceous transplants, and agressive perennials) is given in Table 11. Seeding rates for grasses for each of four vegetation types and three degree-of-wetness sites are displayed in Table 12.[1/]

[1/] Monsen, S. B., "Rehabilitation on Forest Roads," Training Session and Field Tour, 19-20 September 1973, Intermountain Forest and Range Experiment Station, with the cooperation of the Boise National Forest, Payette National Forest, and the Idaho State Department of Highways, Boise, Idaho.

TABLE 10

TREE AND SHRUB SPECIES BEING GROWN AT THE LUCKY PEAK NURSERY FOR SOIL STABILIZATION PURPOSES AND THEIR ECOLOGICAL SITE ADAPTATION

	Ecological Site Adaptation		
Species	Dry Sites (Mountain Brush)	Intermediate Sites (Ponderosa Pine)	Moist Sites (Douglas Fir)
Alder, Thinleaf			X
Barberry, Creeping		X	X
Bearberry			X
Bitterbrush, Antelope	X	X	X
Bladdersenna	X	X	
Ceanothus, Deerbrush		X	X
Ceanothus, Redstem			X
Ceanothus, Snowbrush	X	X	X
Ceanothus, Squawcarpet		X	X
Ceanothus, Wedgeleaf	X		
Cherry, Bessey	X	X	X
Cherry, Bitter	X	X	
Chokecherry, Black	X	X	
Cinquefoil, Bush		X	X
Dogwood, Redosier		X	X
Elder, Blueberry	X	X	
Eriogonum, Sulfur	X	X	
Honeysuckle, Tatarian	X	X	
Juniper, Common		X	
Locust, Black	X		
Oceanspray, Bush	X	X	
Penstemon, Bush		X	
Pine, Lodgepole		X	X
Pine, Ponderosa		X	X
Rose, Woods	X	X	X
Sagebrush, Big	X		
Sagebrush, Mountain			X
Serviceberry, Saskatoon	X	X	
Snowberry, Common		X	X
Snowberry, Mountain	X	X	
Spirea, Douglas	X	X	
Sumac, Rocky Mountain	X		
Virginsbower, Western	X	X	
Willow, Scouler		X	X
Wormwood, Oldman	X	X	

TABLE 11

PLANT MATERIALS FOR SPECIAL USES

Companion Seedings	Herbaceous Transplants	Aggressive Perennials
Mountain Rye	Western Yarrow	Smooth Bromegrass, Southern Types
Annual Rye	Louisiana Sage	Intermediate Wheatgrass
Yellow Sweetclover	Aster spp.	Rushleaf Wheatgrass
Timothy	Goldenrod spp.	Pubescent Wheatgrass
Orchardgrass	Fireweed	Tall Oatgrass
	Cinquefoil	Mountain Bromegrass

TABLE 12

GRASS SEEDING RATES FOR THE MAJOR VEGETATION HABITAT TYPES

	Wet Sites		Intermediate Sites				Dry Sites	
	Subaline Fir/ Grand Fir		Douglas Fir		Ponderosa Pine		Mountain Brush	
	kg/ha	lb/acre	kg/ha	lb/acre	kg/ha	lb/acre	kg/ha	lb/acre
Smooth Bromegrass								
Southern Type (Lincoln)	2	2	3	3	4	4	4	4
Northern Type (Manchar)	6	5	6	5	4	4	3	3
Intermediate Wheatgrass (Greenar, Amur, Oahe)			3	3	3	3	3	3
Pubescent Wheatgrass (Luna)			2	2	3	3	3	3
Slender Wheatgrass	3	3	2	2	2	2	1	1
Tall Oatgrass	2	2	2	2	2	2	2	2
Orchardgrass (Potomac)	2	2	1	1	1	1	1	1
Timothy	1	1	1	1	1	1		
Meadow Foxtail	2	2	2	2	1	1		
Kentucky Bluegrass	2	2	1	1	1	1	1	1
Meadow Bromegrass	1	1	1	1				
Hard Fescuegrass					1	1	3	3
Fairway Wheatgrass	—	—	—	—	—	—	2	2
Total[a]	22	20	26	23	26	23	26	23

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[a] Totals of kilograms per hectare do not add because of rounding of small numbers.

IV. GUIDELINES FOR SEDIMENT REDUCTION IN THE IDAHO BATHOLITH

Guidelines for reducing erosion along forest roads include:

1. Locate the forest road away from streams and on soils and geologic materials that are as stable as possible. This presupposes the existence of a detailed soil and geologic map preferably coupled with an on-the-ground survey prior to construction.

2. Keep road beds as narrow as possible and therefore the cuts and fills at a minimum slope gradient and minimum volume, respectively, for each road prism.

3. Collect soil samples and have their fertility tested.

4. Plan the cut and fill vegetation establishment before actual road construction. This planning should include assured sources of supplies of lime, fertilizer, seeds, plants, mulches, and machinery or manpower for application and planting.

5. Where possible and economical, strip the topsoil from the construction site and stockpile it for spreading on the cut and fill slopes to make a better plant environment and to preserve native seeds and plants.

6. When the final grade of the cut and fill slopes have been established, immediately apply an organic mulch of some suitable material to protect the soil and provide additional needed surface treatment such as compaction with a sheepsfoot roller, soil stabilizing chemicals, or other erosion-retarding methods. Lime can be added on bare soil or on top of the mulch at any season except when the surface is frozen.

7. Apply the optimum amount and kind of fertilizer called for by the soil test by spreading it on bare soil or on top of the mulch. Lime and fertilizer should not come in contact with each other.

8. Apply seed or set plants, whatever species are recommended, at the proper season, on bare soil or through the mulch. Ponderosa pine ceanothus, elder, sage, willow, and elderberry are examples of recommended species to plant.

9. Inspect the areas at least once each season for the following 2 years and replant the spots where a good stand of plants does not exist.

10. Provide for maintenance of road drainage structures to assure proper operation over time.

V. SOURCES OF ASSISTANCE

The principal sources of assistance in stabilizing soils along forest roads and other construction slopes in the Idaho Batholith include:

Boise National Forest
1075 Park Boulevard
Boise, Idaho 83706
208-342-2711

Intermountain Forest and Range Experiment Station
Forestry Sciences Laboratory
P.O. Box 469
1221 South Main Street
Moscow, Idaho 83843
208-882-3557

Intermountain Forest and Range Experiment Station
Headquarters
507 25th Street
Ogden, Utah 84401
801-399-6361

Intermountain Forest and Range Experiment Station
Research Work Unit
360 East Myrtle Street
Boise, Idaho 83706
208-342-2711

Payette National Forest
Forest Service Building
McCall, Idaho 83638
208-634-2255

State of Idaho Transportation Department
Division of Highways
P.O. Box 7129
Boise, Idaho 83707

VI. ADDITIONAL REFERENCES

Clayton, J. L., "Clay Mineralogy of Soils in the Idaho Batholith," Geological Society of America Bulletin, 85:229-232, February 1974.

Clayton, J. L., and J. F. Arnold, "Practical Grain Size, Fracturing Density and Weathering Classification of Intrusive Rocks of the Idaho Batholith," Intermountain Forest and Range Experiment Station, General Technical Report INT-2, U.S. Forest Service, 17 pages, October 1972.

Clayton, J. L., and C. E. Jensen, "Water Retention of Granitic Soils in the Idaho Batholith," Intermountain Forest and Range Experiment Station Research Paper INT-143, U.S. Forest Service, 20 pages (1973).

Foiles, M. W., and J. D. Curtis, "Regeneration of Ponderosa Pine in the Northern Rocky Mountain--Intermountain Region," USDA Forest Service Research Paper INT-145, 44 pages (1973).

Lowman, B., D. McKenzie, and D. Hallman, "Investigation of Selected Problems in Range Habitat Improvement," Range Ecosystems Improvement Practices, USDA Forest Service, ED and T 2358, 45 pages (1974).

Meeuwig, R. O., "Soil Stability on High Elevation Rangeland in the Intermountain Area," Intermountain Forest and Range Experiment Station Research Paper INT-94, U.S. Forest Service, 10 pages, May 1971.

Megahan, W. F., "Logging, Erosion, Sedimentation--Are They Dirty Words?," Journal of Forestry, 70(7), July 1972.

Megahan, W. F., "Role of Bedrock in Watershed Management," Proceedings, Irrigation and Drainage Division Specialty Conference, American Society of Civil Engineers, Fort Collins, Colorado, 22-24 April 1973.

Megahan, W. F., "Erosion Over Time on Severely Disturbed Granitic Soils: A Model," Intermountain Forest and Range Experiment Station Research Paper INT-156, U.S. Forest Service, 14 pages (1974).

Megahan, W. F., "Sedimentation in Relation to Logging Activities in the Mountains of Central Idaho," Proceedings, Sediment Yield Workshop, Oxford, Mississippi, 28-30 November 1972. (In press 1974).

Nelson, D. O., J. F. Arnold, and W. J. Leighty, "Soil Survey of the Middle Fork Payette River Area, Idaho," U.S. Department of Agriculture, U.S. Forest Service, in cooperation with the Soil Conservation Service, and the Idaho Agricultural Experiment Station (University of Idaho), 247 pages mimeographed (1969).

Packer, P. E., "Criteria for Designing and Locating Logging Roads to Control Sediment," Forest Science, 13(1):2-18, March 1967.

Packer, P. E., and H. F. Haupt, "The Influence of Roads on Water Quality Characteristics," Proceedings, Society of American Foresters, Detroit, Michigan, pp. 112-115 (1965).

Pfister, R. D., R. Steele, R. A. Ryker, and J. A. Kittams, "Preliminary Forest Habitat Types of the Boise and Payette National Forests," Intermountain Forest and Range Experiment Station (RWU-1205 and RWU-1651), and Region 4, U.S. Forest Service, 61 pages, May 1973.

"Soil Management Report, Garden Valley Ranger District, Boise National Forest," (Emmett Ranger District was organized mostly from the Garden Valley Ranger District), 116 pages, undated.

"Technical Standards and Specifications--Critical Area Planting," Idaho USDA Soil Conservation Service, 3 pages (1971).

"Water Quality Protection Guide--Logging Roads," U.S. Environmental Protection Agency, Region 10, 1200 Sixth Avenue, Seattle, Washington 98101 (Draft), August 1974.

Wendt, G. E., D. B. Layton, and E. N. Dean, "Soil-Hydrologic Reconnaissance Survey, Emmett Ranger District, Boise National Forest," June 1973.

NEW MEXICO

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NEW MEXICO--DEMONSTRATION AREA NUMBER 3

TWELVE MILES OF ROADSIDE REVEGETATION ALONG THE LORDSBURG BYPASS

Summary

Establishment of vegetation on 162 ha (400 acres) along 19 km (12 miles) of Lordsburg Bypass Highway in Hidalgo County in southwestern New Mexico may be considered typical of the Southern Desert. The principal constraint was low annual rainfall, which averaged slightly less than 25 cm (10 in.). A second constraint was poor rainfall distribution, April and May receiving less than adequate rainfall for the growth of vegetation. The deficiency must be made up by moisture stored in the soil. The soil was fine-textured and typicl of the Great Group of Haplargids (dry soils). The seeding date considered ideal was June because this precedes the 3-month period when half of the annual rainfall is received. A seedbed should be prepared to a depth of 15 to 20 cm (6 to 8 in.) to assure rapid moisture infiltration and adequate storage. Mulching with wild, long, grass hay cut into the seedbed with a dull disk set flat is necessary after seeding. Soil nutrient testing is now recommended but was not practiced when the Lordsburg Bypass was fertilized with nitrogen and phosphorus. The five grasses and one shrub that were successfully seeded are all native to the Southern Desert. Irrigation at the rate of 2.5 cm (1 in.) a week for 7 weeks was necessary to assure successful seedling establishment.

I. INTRODUCTION

A. Background

New Mexico is located in the southeastern part of the Southern Desert. Other States that are partially in the Southern Desert are Texas, Arizona, California, Nevada, and Utah. Population density is low in all desert areas, and in New Mexico it is three persons per square kilometer (eight persons per square mile). In the Southern Desert there is a fragile balance among sparse vegetation, highly erodible soils, and intense rainfall.

Land use in New Mexico includes rangeland - 75%; forest - 19%; cropland - 5%; and pasture and other uses - 1%.

Pursuant to Section 204(e) of Public Law 92-500, and at the request of the U.S. Environmental Protection Agency, the New Mexico State Highway Department[1/] has prepared an interim draft on an erosion abatement plan that includes the following provisions:

1. "All waterways resulting from construction activities shall carry water with a nonerosive maximum velocity of 2-1/2 ft/sec (0.76 m/sec). Such a criterion permits the successful establishment of vegetation in water channels."

2. "Raw soil surfaces shall be protected as soon as an area of 20 x 1,320 ft (6.1 x 402 m) is exposed. This protection shall consist of an approved mulch material if the final grade has not been attained, or a permanent seeding of an approved seeding mixture if the final grade has been achieved."

3. "Immediately following the completion of grading operations, the following procedures shall be performed: ripping the soil to a depth of 6 to 8 in. (15 to 20 cm), fertilizing according to the terms of the contract, seeding of the approved mixture, and applying the recommended amount and kind of mulch."

B. The Demonstration Area

The demonstration area is Hidalgo County which is located in southwestern New Mexico (Figure 33). Elevations in the county are generally between 1,219 m (4,000 ft) and 1,524 m (5,000 ft), with two mountain peaks reaching about 2,591 m (8,500 ft). Most of the county has only interior drainage, i.e., water flows into closed basins (playas).[2/]

[1/] New Mexico State Highway Department, "Erosion Abatement Plan: Erosion Control Policy and Guidelines," Interim Draft of Multidisciplinary Committee, 26 pages, 22 November 1974.

[2/] New Mexico State University, "Soil Associations and Land Classification for Irrigation, Hidalgo County," New Mexico State University in cooperation with the Water Resources Research Institute and the Soil Conservation Service, Research Report 177, Las Cruces, New Mexico, 29 pages, August 1970.

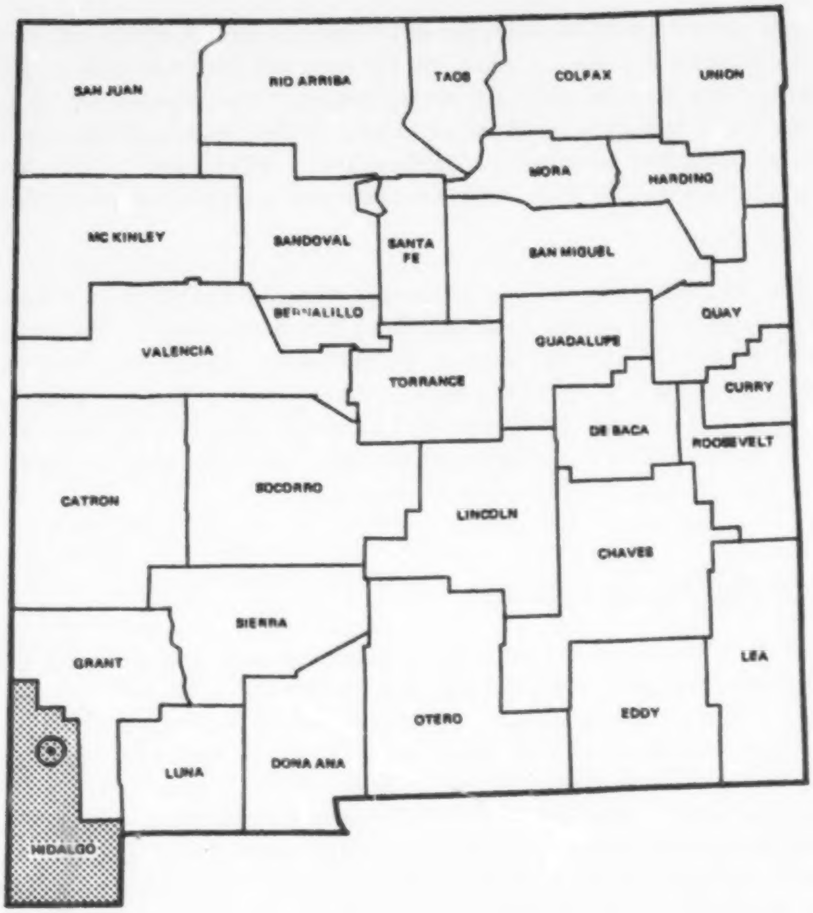
SAN JUAN
RIO ARRIBA
TAOS
COLFAX
UNION
MORA
HARDING
MC KINLEY
SANDOVAL
SANTA FE
SAN MIGUEL
BERNALILLO
QUAY
VALENCIA
GUADALUPE
TORRANCE
CURRY
DE BACA
ROOSEVELT
CATRON
SOCORRO
LINCOLN
CHAVES
SIERRA
GRANT
LEA
OTERO
EDDY
LUNA
DONA ANA
HIDALGO

Figure 33 - Map of New Mexico Showing the Location of Hidalgo County, the Demonstration Area, and the Demonstration Site at Lordsburg, Shown by a Circle, in the Northeastern Part of the County

C. The Demonstration Site

The demonstration site is a 19-km (12-mile) strip of roadside along the Lordsburg Bypass, a part of Interstate 10 from Tuson, Arizona, to Las Cruces, New Mexico, and El Paso, Texas. The elevation is approximately 1,294 m (4,245 ft). All road cuts, fills, and medians were seeded to a permanent mixture of grasses during 1967, 1973, and 1974. In addition, 10 ha (25 acres) of the east section was overseeded with four-wing saltbush.

The 162 ha (400 acres) of exposed soils along the 19-km (12-mile) bypass comprised 65 ha (160 acres) of cut slopes, 61 ha (150 acres) of fill slopes, and 36 ha (90 acres) of medians. Since the bypass was mostly in an east-west direction, most of the slopes faced either north or south. The slopes had a maximum height of 7.6 m (25 ft) and a maximum grade of 3:1. The most common slope was 1.5 m (5 ft) in vertical height on a 6:1 grade.

D. Climate and Plant Environment

In the Southern Desert, precipitation and its distribution are the dominant factors controlling the choice of grasses for seeding on disturbed soils (Figure 34).[1/] Grasses that perform at their optimum when winter moisture is dominant are: crested wheatgrass, Siberian wheatgrass, and pubescent wheatgrass. Species that grow least with summer moisture are: Russian wildrye, Lehmann lovegrass, weeping lovegrass, sideoats gramagrass, and black gramagrass. Three grasses perform at their optimum in a moisture regime when either winter or summer rainfall is dominant: big bluegrass, hard fescuegrass and orchardgrass.

The climate of Hidalgo County is continental, arid to semiarid, and with large differences in temperatures day-to-night and season-to-season. The county averages 28 cm (11 in.) of annual precipitation, and the range is from about 23 to 51 cm (9 to 20 in.), varying directly with elevation.

[1/] Currier, W. F., "Basic Principles of Seeding Critical Areas," Proceedings, Critical Area Stabilization Workship, Report 7, New Mexico Inter-Agency Range Committee, Albuquerque, New Mexico, pp. 106-111, 27-29 April 1971.

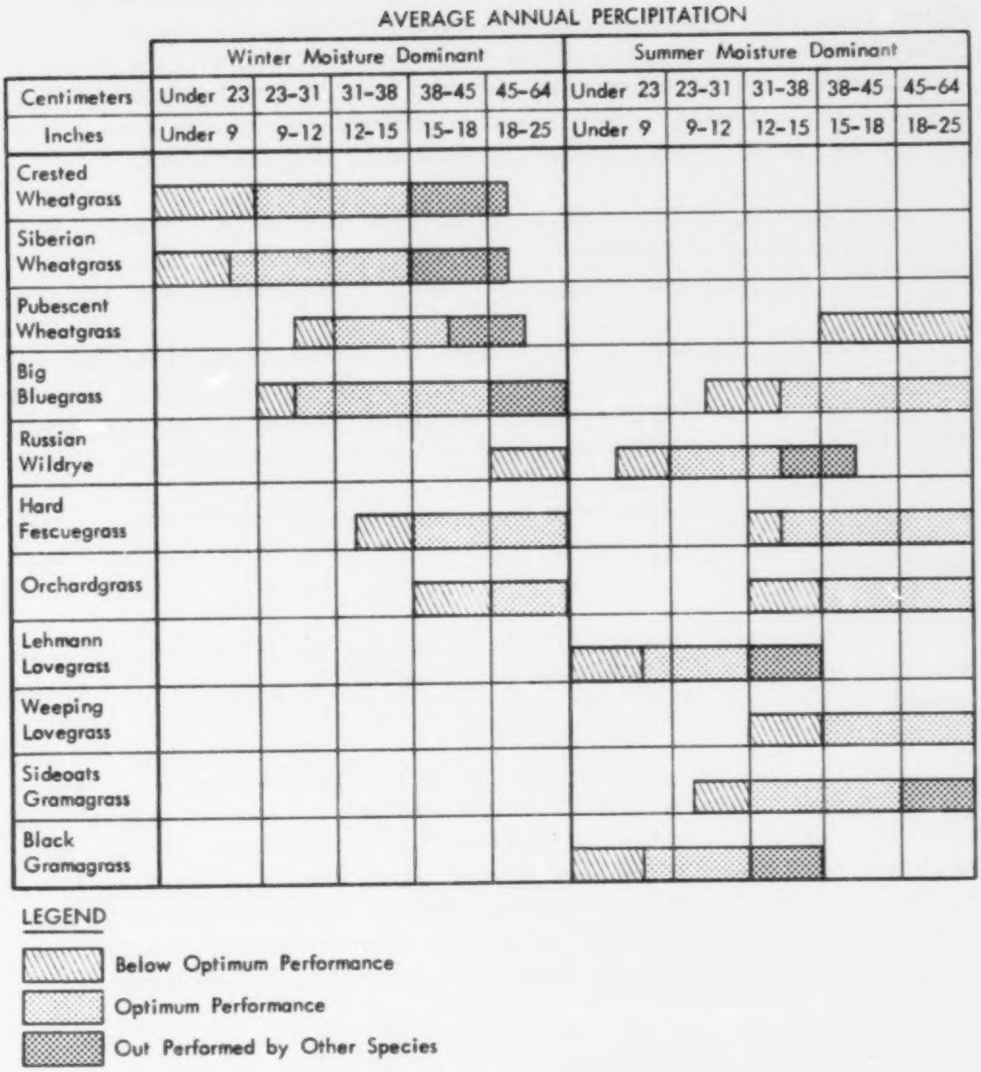

Figure 34 - Annual and Seasonal Precipitation Determine the Choice of Grass Species to Seed on Disturbed Soils

At the Lordsburg demonstration site, the annual rainfall averages 24.84 cm (9.78 in.). Half of the annual precipitation is received during July, August, and September. This means that seeding dates must be adjusted to take advantage of this water (Figure 35). Rainfall during other months varies from 0.53 cm (0.21 in.) in May to 2.21 cm (0.87 in.) in October. With the general assumption that grasses need at least 0.5 cm (0.2 in.) of water every 2 weeks, moisture stress is experienced in the average year during the months of April, May, and June.

At Lordsburg, there is a freeze-free period of 215 days, normally from 3 April to 4 November. Mean daily temperatures reach a high of 28°C (82°F) in July and a low of 6°C (43°F) in December and January.

Relative humidity is the lowest in April and May when the rainfall also is lowest. During these months, morning readings are about 40%, dropping to 20% in the midafternoon. During the other 10 months, the readings are 65 to 35%, in morning and afternoon, respectively.

Winds are predominantly from the southwest and are mostly under 40 km/hr (25 mph). Again, spring winds are the strongest and fall winds are the lightest.

Sunshine averages 85% of the possible, or 3,700 hr/year. Evaporation from an open water surface is 234 cm (92 in.) a year, 9.4 times the annual rainfall.

At the Lordsburg demonstration site, available water is the principal deterrent to the establishment and maintenance of vegetation, especially on soils disturbed by construction activities. The two most critical months are April and May, during which time the rainfall is least, the relative humidity is lowest, and the wind speeds are highest. The net result is moisture stress for plants caused by a limited supply of water in the soil and very high rates of transpiration and evaporation.

II. SOILS AND UNDERLYING GEOLOGIC MATERIALS

The predominant soil series on the Lordsburg Bypass is Tres Hermanos, a Typic Haplargids (dry soils), fine-loamy texture, mixed mineralogy, and thermic temperature regime. The Haplargids Great Group of soils is extensive, comprising 685,000 km^2 (264,000 miles^2) and 7.48% of the land area of the United States.

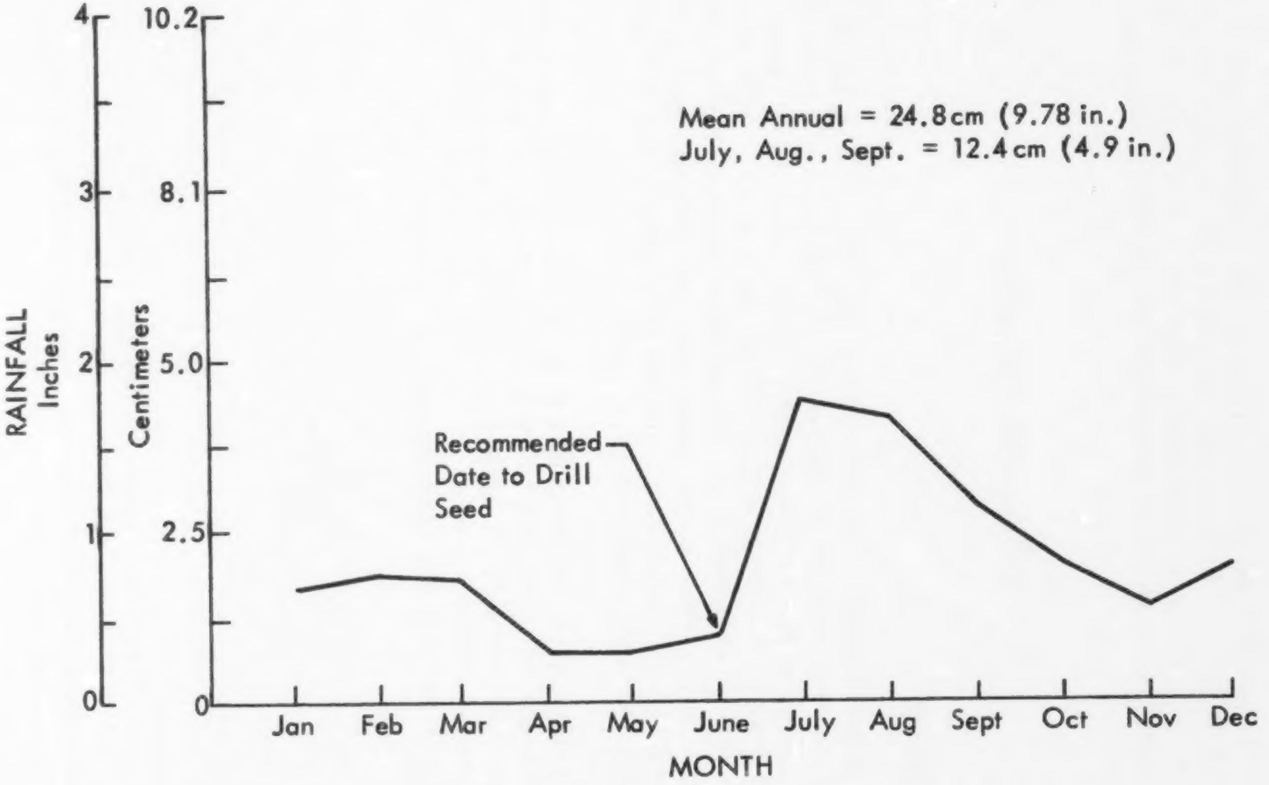

Figure 35 - Mean Monthly Precipitation for Lordsburg, New Mexico (southern desert area) in Relation to the Recommended Date to Drill Seed on Construction Sites

Tres Hermanos soils occur on slopes of 0 to 5%. The surface is typically a light brown gravelly sandy clay loam over a reddish-brown gravelly clay loam subsoil that is very high in lime. Below the subsoil is a pinkish-white limey, very gravelly loam.

The eastern and western sections of the Lordsburg Bypass have stony clay surface soils; whereas, the texture of the surface of the central section is a gravelly clay loam. The soils are generally about 1.5 m (5 ft) deep, below which is weathered and partially disintegrated granitic bedrock.

III. ESTABLISHING VEGETATION

A. Plant Selection

The adaptability of selected grass species to soil textural classes in the Southern Desert is portrayed in Figure 36.[1] From this figure, the conclusion can be drawn that optimum growth of Siberian wheatgrass and black gramagrass will occur on sand soils. On loam soils, optimum growth can be expected from crested wheatgrass, Siberian wheatgrass, pubescent wheatgrass, black gramagrass, and sideoats gramagrass. Three grasses, pubescent wheatgrass, western wheatgrass, and sideoats gramagrass attain optimum growth on clay soils.

The plants selected for seeding on the Lordsburg Bypass were those native species of known origin that had performed satisfactorily during previous years at similar locations. No exotic species were selected. The seeding mixture used on all areas, the origin of the seed, and the pounds per acre in the mixture were as follows:

---

[1] Currier, W. F., "Basic Principles of Seeding Critical Areas," _Proceedings_, Critical Area Stabilization Workshop, Report 7, New Mexico Inter-Agency Range Committee, Albuquerque, New Mexico, pp. 106-111, 27-29 April 1971.

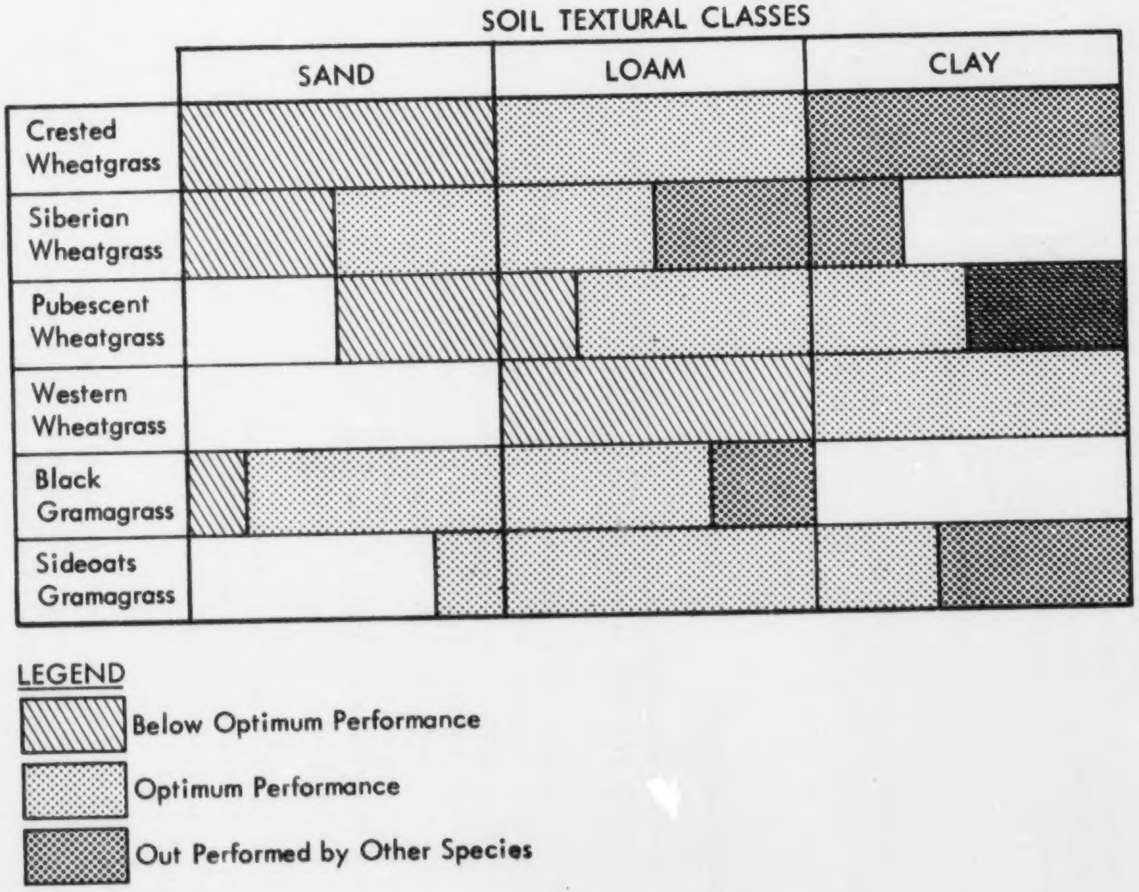

Figure 36 - Adaptability of Some Grass Species to Soil Texture in the Southern Desert

Species	Origin	Seeding Amounts	
		kg of live seed/ha	lb of live seed/acre
Sideoats Gramagrass	Vaughn, New Mexico	5.6	5.0
Blue Gramagrass	Lovington, New Mexico	2.2	2.0
Black Gramagrass	Marfa, Texas	2.2	2.0
Lehmann Lovegrass	New Mexico	2.2	2.0
Alkali Sacaton	Arizona	1.1	1.0
Total		13.4	12.0

In addition, four-wing saltbush was overseeded on the eastern area at the amount of 4.5 kg of live seed per hectare (4 lb of live seed per acre).

B. Seedbed Preparation

Seedbed preparation on the Lordsburg Bypass was the same as that specified by the New Mexico State Highway Department[1] as follows:

> "The seedbed shall be prepared to a minimum depth of 10 cm (4 in.) [in 1974 changed to 15 to 20 cm (6 to 8 in.)] by tilling with a disc harrow or chiseling tools. All competitive vegetation shall be uprooted during seedbed preparation and the soil shall be uniformly worked to a smooth firm surface free of clods, large stones of over 10 cm (4 in.) in any dimension or other foreign material that would interfere with seeding equipment.
>
> "All tillage must be performed across the slope when practical. No work shall be done when the moisture content of the soil is unfavorable or the ground is otherwise in a nontillable condition.
>
> "The extent of seedbed preparation shall not exceed the area on which the entire seeding operation can be applied to such prepared seedbed within a 24-hr period."

---

[1] New Mexico State Highway Department, Supplemental Specifications for Seeding, Section 771, Revised 28 November 1972.

C. Fertilizing

The Lordsburg Bypass demonstration site was uniformly fertilized by drilling to a depth of 1.3 cm (1/2 in.), 224 kg/ha (200 lb/acre) of 16-20-0. No soil testing for determining the fertilizer needs of the soil was performed, although it is now a recommended practice.

D. Seeding

The seeding mixture of the five grasses was drilled to a depth of 1.3 cm (1/2 in.). On the upper part of the steeper slopes, the mixture was broadcast and harrowed into the soil. The seeds of four-wing saltbush also were drilled over the established stand of grasses. The dates of seeding varied between 15 June to 15 September, although the month of June is considered the best seeding period. Dry-seeding in June permits the seeds to utilize the higher rainfall during the months of July, August, and September, and a long growing temperature before frost.

E. Mulching

Grass hay mulch, 5.6 mt/ha (2-1/2 tons/acre), was anchored into the soil by spreading and then running a dull disk over the hay. The disk was set flat so as not to throw any soil.

Specifications on mulch by the New Mexico Highway Department are as follows:

> "Hay Mulch. Perennial native or introduced grasses of fine-stemmed varieties shall be used. At least 65% of the herbage by weight of each bale of hay must be 25 cm (10 in.) in length or longer. Hay with noxious seed or plants will not be acceptable. Rotted, brittle, or molded hay will not be acceptable. Marsh grass or prairie hay composed of native grass of species to be seeded will be acceptable. Tall wheat grass intermediate wheat grass, switch grass or orchard hay will be acceptable if cut prior to seed formation. Marsh grass hay shall be composed of mid and tall native, usually tough and wiry grass and grass-like plants found in the lowland areas within the Rocky Mountain Region."

"Wood Fiber Mulch. Mulch shall be produced from Aspen wood and shall be 0.06 cm (0.024 in.) by 0.08 cm (0.030 in.), plus or minus 30% and a minimum of 65% of the fibers shall be 25 cm (10 in.) or longer in length. The material shall be air dried to a maximum 18% moisture content at the time of shipping, and free of mold or fungus."

F. Irrigation

The seeding at Lordsburg Bypass was irrigated at the rate of 2.5 cm (1 in.) per acre or water volume amounting to 102 m^3 (27,100 gal.) each week for a period of 7 weeks, starting immediately after seeding and mulching.

G. Evaluation

In August of 1974, an evaluation of the mean density of all seedings on the 160 ha (400 acres) was made with the use of a square metal frame. The frame was tossed 150 times over the entire grass seeding and 30 times over the seeding of four-wing saltbush. The mean densities were as follows:

	Mean Density	
Species	plants/m^2	plants/ft^2
Grasses		
Sideoats Gramagrass	64	6.0
Lehmann Gramagrass	32	3.0
Blue Gramagrass	16	1.5
Black Gramagrass	9	0.8
Alkali Sacaton	5	0.5
Total	116	11.8
Shrubs		
Four-Wing Saltbush	32	3.0

The density of the vegetation was judged satisfactory for controlling soil erosion and sediment runoff.

IV. MAINTENANCE

An herbicide, Bromoxynil, has been used with success to control Russian thistle and kochia on highway slopes, especially on slopes that are too long and steep to mow.[1]

Mowing is an alternative to the use of an herbicide to control weed species. Mowing height controls, however, are important to prevent excessive weakening of the established grasses.[2] Recommended minimum mowing heights of common grasses planted on roadsides are:

Species	Minimum Mowing Height	
	cm	in.
Western Wheatgrass	11	4-1/2
Little Bluestem	11	4-1/2
Arizona Fescuegrass	8	3
Sand Dropseed	8	3
Sideoats Gramagrass	4	1-3/4
Black Gramagrass	4	1-3/4
Alkali Sacaton	4	1-1/2
Buffalograss	4	1-1/2
Blue Gramagrass	3	1-1/4

---

[1] Brammer, R. L., M. A. Fleig, and R. G. Lohmiller, "Highlights from Progress Reports on Herbicides Testing for Weed Control Along Highway Rights-of-Way, and Recommended Methods and Materials," New Mexico State Highway Department and Soil Conservation Service, USDA, 12 pages (undated).

[2] Fleigh, M., "Mechanical Vegetation Control and Maintenance," Proceedings, Critical Area Stabilization Workshop, New Mexico Inter-Agency Range Committee, Albuquerque, New Mexico, pp. 185-187, 27-29 April 1971.

V. ANALYSIS AND CONCLUSIONS

Soils of the Southern Desert are difficult to vegetate primarily because of water stress. Low rainfall creates special problems in relation to cultural practices such as depth of seedbed preparation, geographic source of seed fertilization, seeding rate, mulching, and irrigation.

In general, the lower the annual rainfall in an area, the larger is the percentage that comes as high intensity thunderstorms. In such areas of low total rainfall, all of the water should be encouraged to infiltrate the soil. Practices to encourage more and faster infiltration include a dense mulch and a deep rootbed. At least 4.5 mt/ha (2 tons/acre) of long grass hay and a rootbed loosened to a depth of 15 to 20 cm (6 to 8 in.), should be adequate.

Fertilizers have been accused of killing small seedlings when moisture is limited. An experiment to test this hypothesis was reported by Williams.1/

A greenhouse pot test with German millet and mohave sandy loam tested the foregoing hypothesis. This soil belongs to the same soil family as the Tres Hermanos series on the Lordsburg Bypass demonstration site. The results are summarized by the author as follows:

> "Germination of black gramagrass was increased by fertilizer treatments. The only treatment which decreased germination was the phosphorus alone which decreased side-oats gramagrass germination significantly. This decrease was not apparent when nitrogen was combined with phosphorus. Fertilizing mohave sandy loam soil with the levels of fertilizer used in this experiment should not inhibit germination.
>
> "No significant increase was found in the number of leaves per plant due to fertilizer treatment.

1/ Williams, B. C., "Fertility Status of Fifteen New Mexico Soil Types," New Mexico State University Agricultural Experiment Station Bulletin No. 445, 18 pages (1960).

> "The nitrogen level was too low to give a significant response alone when measured by increase in leaf length and oven dry weight for black gramagrass and side-oats gramagrass. Nitrogen showed a significant influence on growth rate of galleta when used alone.
>
> "Phosphorus alone significantly influenced the growth rate of all three species, except for the oven dry weight of galleta.
>
> "The interaction of nitrogen and phosphorus gave significantly greater response in rate of plant growth for all species.
>
> "Low levels of nitrogen and phosphorus fertilizer should be beneficial in improving seedling establishment on mohave sandy loam."

There was no soil testing on the Lordsburg Bypass but the Highway Department is convinced of its necessity. As a rule-of-thumb, sand soils should have 67 kg/ha (60 lb/acre) of nitrogen (N) fertilizer, clay soils 101 kg/ha (90 lb/acre), and both soils 56 kg/ha (50 lb/acre) of phosphorus (P_2O_5) fertilizer to assure satisfactory growth of vegetation.

On slopes not mowed, woody plants such as four-wing saltbush, are recommended. Some native woody and herbaceous plants were removed from wild areas and transplanted to roadside slopes. Nursery grown shrubs, trees, and vines were grown in plastic tubes and transplanted with success.

Hydroseeding has been tried, but it does not produce satisfactory results in areas receiving less than 46 cm (18 in.) of annual precipitation. In New Mexico, only a few mountainous areas receive this much precipitation.

Because of the severe moisture stresses which are always present in Southern Desert soils, all plant species seeded or planted should be those that have been previously tested under similar low rainfall conditions. In this regard, the New Mexico State Highway Department has been cooperating since 1966 with the Soil Conservation Service and the New Mexico State University in the collecting of seed and the testing of plant species at the Plant Materials Center at Los Lunas, New Mexico. The problem of satisfying all agencies on the selection of species is summarized as follows: The State Game Department does not want a species palatable to deer and elk; ranchers want a species highly palatable to domestic livestock; farmers do not want a "weed" species; but the State Highway Department wants anything that will grow and hold the soil in place.

Topsoiling in New Mexico is not a common practice because of the thinness of the existing topsoil. On the Lordsburg Bypass, no topsoiling was done for this reason. A modification of texture (plating) is practiced in the State, but it was not necessary on the Lordsburg Bypass. This practice of texture modification is common on very fine textured clays (on which sand is plated) and coarse textured sands (on which clay is plated).

Chemical polymers were tried in New Mexico, but they could not compete in price or effectiveness with long hay mulch in assisting in vegetation establishment.

The ideal planting date is June, immediately prior to the 3 months during which half of the annual rainfall is received. Seedings made before June may germinate and die for lack of moisture.

VI. FURTHER RESOURCE INFORMATION

The principal source of further information on establishing and maintaining vegetation on soils disturbed by construction activities is the New Mexico Inter-Agency Range Committee. Membership comprises officials from: the U.S. Agricultural Research Service, U.S. Agricultural Stabilization and Conservation Service, U.S. Bureau of Indian Affairs; U.S. Bureau of Land Management; U.S. Forest Service; U.S. Soil Conservation Service; New Mexico Grass Seed Growers and Dealers; New Mexico Crop Improvement Association; New Mexico Game and Fish Department; New Mexico Property Appraisers Department; New Mexico State Land Office; New Mexico State University Agricultural Services (specialists in range science, animal science, and soil science); New Mexico State Highway Department; and private ranchers. For published information, contact:

Agricultural Research Service
U.S. Department of Agriculture
P.O. Box 698
Las Cruces, New Mexico 88001

County Extension Agent
Box 280
Lordsburg, New Mexico 88045

Department of State Forestry
P.O. Box 2167
Santa Fe, New Mexico 87501
505-827-2312

Environmental Improvement Agency
P.O. Box 2348
Santa Fe, New Mexico 87501
505-827-2473

Extension Service
New Mexico State University
Las Cruces, New Mexico 88003
505-646-1806

New Mexico Association of Soil and Water
Conservation Districts
Department of Agriculture
P.O. Box 3189
Las Cruces, New Mexico 88003
505-646-3007

New Mexico Conservation Coordinating Council
P.O. Box 142
Albuquerque, New Mexico 87103 or

Larry T. Caudill, President
915 Washington Street, S.E.
Albuquerque, New Mexico 87108

Soil Conservation Service
517 Gold Avenue, S.W.
P.O. Box 2007
Albuquerque, New Mexico 87101

State Department of Agriculture
P.O. Box 3189
Las Cruces, New Mexico 88003
505-646-3007

State Highway Department
Santa Fe, New Mexico 87501

State Natural Resource Conservation Commission
321 West San Francisco Street
Santa Fe, New Mexico 87501
505-646-1806

U.S. Forest Service
519 Gold Avenue, S.W.
Albuquerque, New Mexico 87101

VII. ADDITIONAL REFERENCES

Aldon, E. F., "Revegetating Disturbed Areas in the Semiarid Southwest," Journal of Soil and Water Conservation, pp. 223-225, September/October 1973.

"Critical Area Stabilization in New Mexico," Recommendations prepared at the 27-29 April 1971 Critical Area Stabilization Workshop, sponsored by the New Mexico Inter-Agency Range Committee, Report No. 7, January 1973, 44 pages, U.S. Department of Agriculture, P.O. Box 698, Las Cruces, New Mexico 88001.

"New Mexico Conservation Needs Inventory," Statistical Report, 1966-1967 Inventory, Joint Federal-State Study, 289 pages, January 1970.

"Planting for Wildlands and Erosion Control," University of Nevada, Circular, C108, 24 pages (1970).

Quimby, C. P., "Use of Chemicals in Maintenance of Established Vegetation," Proceedings, Inter-Agency Range Committee, Albuquerque, New Mexico, pp. 174-184, 27-29 April 1971.

"Seeding Nonirrigated Lands in New Mexico," New Mexico Inter-Agency Range Committee, Report No. 10, 95 pages, February 1973.

COLORADO

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COLORADO--DEMONSTRATION AREA NUMBER 4

REVEGETATION OF CUT AND FILL SLOPES ON THE FRONT RANGE OF THE ROCKY MOUNTAINS

Summary

Cut and fill slopes on an 8-mile section of Interstate 70, west of Denver, in the Rocky Mountains, were vegetated satisfactorily. Annual rainfall averages 43 cm (17 in.); the soil is mostly shallow gravelly loam over granite. The areas to be seeded were topsoiled, fertilized, and seeded. A wood fiber mulch was used to control erosion. All seeding and mulching were completed in 1971 and evaluated in the fall of 1974. Regardless of slope aspect, some long, steep slopes had thin ground cover, and erosion rills resulted. Vegetation on fill slopes was superior to that on cut slopes. Crested wheatgrass dominated the cover, followed by intermediate wheatgrass and smooth bromegrass.

I. INTRODUCTION

Extremely coarse-textured infertile substratum has been a long-recognized problem in revegetation of disturbed construction sites within the front range of the Rocky Mountains. Even after decades, only sparse vegetation has been established on steep south-facing cuts into substratum of disintegrated granite, gneiss and schist. Seeding alone has been an unsuccessful revegetation practice. The combination of seeding and fertilization has also generally been unsuccessful--in some places because the soil materials are too coarse and droughty, and in other places because the continuing need for nitrogen fertilization of the infertile substratum was not recognized, or because a fertility maintenance program was not followed because it was considered economically unfeasible.

These problems were recognized by the Colorado Highway Department when planning for the revegetation of cut and fill slopes on Interstate Highway 70 west of Denver. The key to the successful revegetation program on I-70 in this area was found to be the replacement of topsoil which has been salvaged from scalped areas.

A 13-km (8-mile) section of I-70, beginning 17 km (11 miles) west of Denver (Exit 54A) and extending 13 km (8 miles) east to Exit 58, is used to illustrate the following discussion.

Site Description

In this area of hilly to steep topography, the elevation ranges from 2,200 to 2,350 m (7,200 to 7,700 ft). The average annual precipitation is 41 to 46 cm (16 to 18 in.). Bedrock is predominantly gneiss, although some granite is present.

The soils are gravelly loams, shallow to moderately deep over disintegrated rock and in some places hard bedrock. A published soil survey of the area is not available, but the dominant soil series within the area is similar to the Stecum series in the Soil Great Group of Cryorthent, described for the Trout Creek area 130 km (80 miles) to the southeast.[1/] This soil has about a 13-cm (5-in.) surface horizon of a brown gravelly loam over a subsurface horizon about 30 cm (12 in.) thick, which is considerably lighter in color and which may contain 50 to 70% coarse fragments. At depths below 43 cm (17 in.) coarse disintegrated rock and, in places, bedrock are encountered. Vegetation on this soil is visually dominated by scattered ponderosa pine and the shrub mountain mahogany. The dominant grasses are mountain muhly, needle-and-thread, blue gramagrass, and western wheatgrass.

Associated with the relatively shallow soil are areas having deeper soils. In the swales and on gentler slopes a soil similar to the Bassel series (Argicryoboroll) supports vegetation dominated by ponderosa pine, Kentucky bluegrass, and western wheatgrass. On steep north-facing slopes with vegetation dominated by Douglas fir, a soil similar to the Edloe series (Cryoboralf) is found.

These soils are slightly acid to neutral (pH 6 to 7) in reaction and contain 3 to 4% organic matter in the surface horizons, 13 to 20 cm (5 to 8 in.). Organic matter decreases sharply with depth. Plant-available potassium is adequate; phosphorus is usually adequate in the surface horizons and very deficient at greater depths. All soils are very low in soluble salts.

[1/] USDA, Forest Service and Soil Conservation Service, "Soil Survey Trout Creek Watershed Colorado," Series 1958, No. 5, 48 pages plus maps (1961).

The highway is aligned nearly east-west; the cut and fill slopes within the study area are about equally divided between south and north aspects.

II. ESTABLISHING VEGETATION

A. Management Prior to Revegetation

Topsoil was stripped from the portion of the right-of-way to be disturbed. Soil depth stripped was 13 to 15 cm (5 to 6 in.) on the shallower soils to several feet in the swales and drainageways. After the grade was completed, the cuts were topsoiled by hauling back the topsoil and placing it on the steep cuts (60 to 70% slopes) and a maximum height of about 11 m (35 ft) by use of a dragline. Fills were topsoiled by dumping soil over the side. Later investigation showed topsoil depths of 25 to 45 cm (10 to 18 in.) near the bottom of the cuts and 15 cm (6 in.) and less near the top. The topsoil depths were reversed on the fill slopes and sometimes the topsoil did not carry to the bottom (Figure 37).

B. Seeding

Seeding of the eastern portion of the area was completed in the early spring of 1971, and the remainder was seeded in the fall of 1971. Seed was broadcast on the steep cut and fill areas with a hydroseeder. Leveler areas were drilled. The following mixture was specified in the seeding contract for the area:

Species	Pure Live Seed	
	kg/ha	lb/acre
Crested Wheatgrass	5.5	5.0
Intermediate Wheatgrass	3.3	3.0
Western Wheatgrass	6.7	6.0
Smooth Bromegrass	3.3	3.0
Perennial Ryegrass	6.7	6.0
White Clover	2.2	2.0
Ponderosa Pine	0.55	0.5

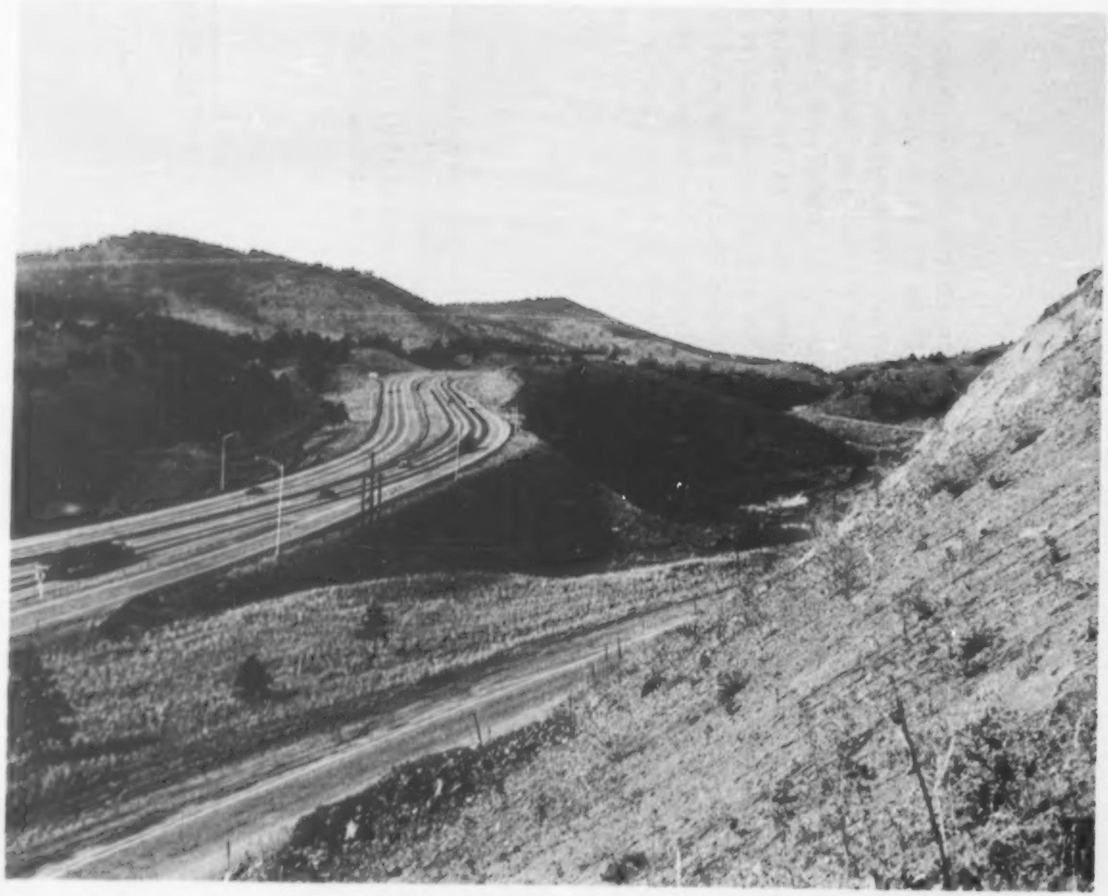

Figure 37 - Bare and Barren Cut Slope on the Demonstration Area in the Rocky Mountains of Colorado. Erosion and sediment yield are high (Courtesy of William Berg, Colorado State University).

The area was mulched with wood fiber at a rate of about 1,700 kg/ha (1,500 lb/acre) and fertilized at the rate of 55 kg N/ha (50 lb N/acre).

Maintenance since seeding has been limited to mowing on the road shoulders. Landscaping was completed by transplanting ponderosa pine up to about 6 m (20 ft) in height into selected settings on the right-of-way.

C. Revegetation Results

Stands were evaluated in the fall of 1974. Overall, the revegetation results were rated as fair to good. As expected in this semiarid area, the north slopes have better stands than the south-facing slopes. Ground cover by living vegetation plus litter on south slopes was estimated as ranging from 30 to 80%. Rilling of the topsoil was obvious on steep south slopes having the thinner ground cover.

North slopes generally had 60 to 80% ground cover. However, several steep north slopes did not have this much cover and rills were evident.

The stands were dominated by crested wheatgrass which made up an estimated 75 to 80% of the cover; intermediate wheatgrass, and to a lesser extent, smooth bromegrass made up most of the rest of the cover. Only scattered western wheatgrass and no perennial ryegrass was found. White clover was found growing only on the road shoulders.

Species that were not mentioned as being in the seeding mix but that were found in scattered stands were sweetclover and slender wheatgrass. Several places on steep south slopes the naturalized winter annual wheatgrass was growing in thick stands. The only native species that invaded a few of the thinner seeded stands was fringed sage.

Overall the vegetation has done a good job of controlling erosion on fill slopes and a fair to good job on cut slopes (Figure 38). The vegetation on the cut and fill slopes of this section of I-70 is in sharp contrast to the nearly bare cuts left by prior highway construction.

Some slips of topsoil down steep north slopes have occurred. This might be avoided by thinner topsoil placement on sites that have been roughened.

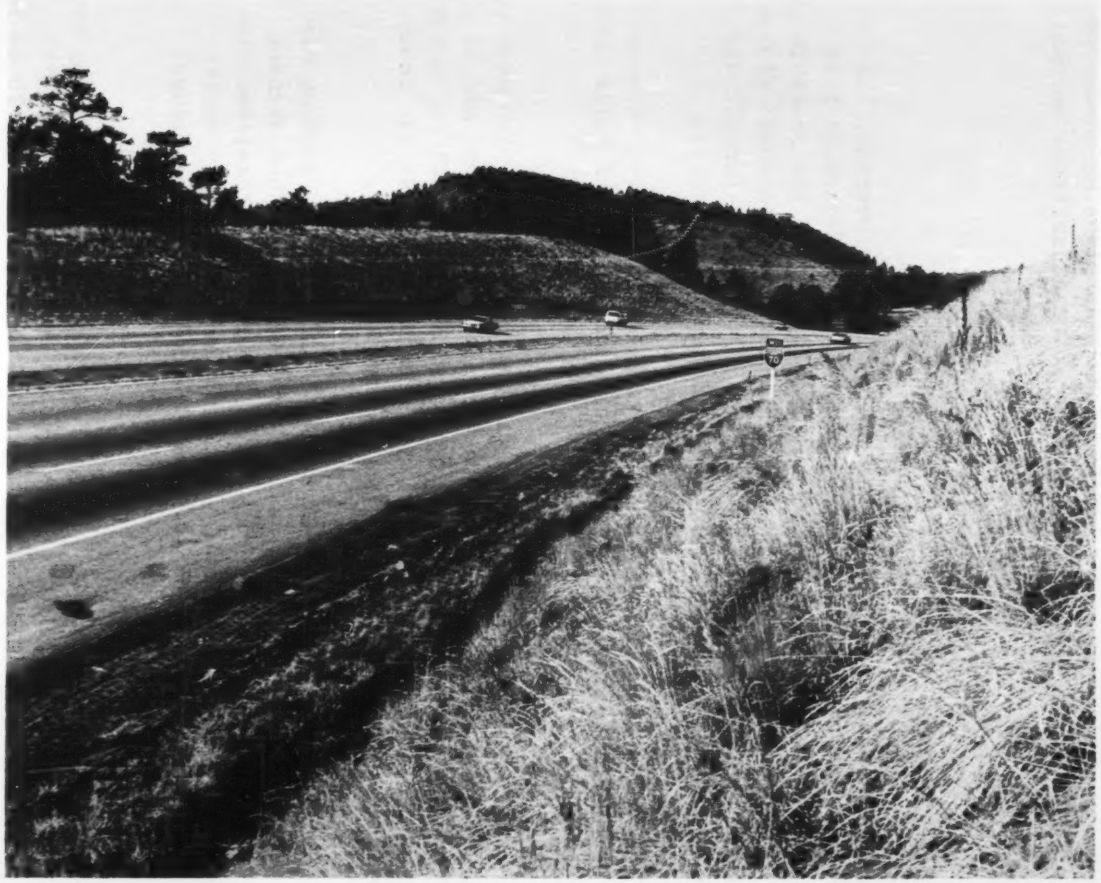

Figure 38 - Revegetated Cut Slope on I-70, 70 Miles West of Denver, Colorado. Erosion and Sediment Have Been Controlled (Courtesy of William Berg, Colorado State University).

III. SUGGESTIONS ON FUTURE REVEGETATION

A. Seeding Operations

Some stands are not as thick as the climate will apparently support. Broadcast seeding which must be used on the steep slopes has definite limitations in a semiarid climate, especially if the soil surface crusts before seeding. This can be resolved on fill slopes by scratching the surface with a chain harrow. The topography and obstruction by trees above the cut slopes do not allow use of this implement. It is suggested that seed be hand broadcast on freshly topsoiled cut slopes daily as the topsoil is placed. Early spring and late fall are the preferred seeding times. Late spring and summer seedings are usually failures.

B. Species

Crested wheatgrass is the dominant species that is selected and seeded. It is outstanding in its ability to establish and persist in this semiarid climate. However, it is a bunch grass that is highly competitive for moisture. On south slopes it tends to form bunchy stands which successfully prevent invasion by other perennial species. Areas between bunches are subject to erosion. Another problem with crested wheatgrass in this area is that it starts growth very early in spring and will green up again in the fall if moisture is adequate. This somewhat unseasonable forage attracts deer, which can cause a traffic hazard.

It is difficult to leave this species out of the seeding mixture, as it is the one species that can be relied upon to become established on the south-facing sites. One should consider using it and increasing the seeding rate of other species, particularly western wheatgrass, specifically calling for the recently introduced "Arriba" western wheatgrass selection from eastern Colorado.

The mixture used on south-facing slopes could also be expanded to include sideoats gramagrass and Indian ricegrass. Kentucky bluegrass should be included in the mix for north-facing slopes.

A legume is needed in the mixtures. White clover which was used is not adapted to the drier upland sites. Self-reseeding of the biennial sweetclover is undependable, and this species is overly competitive the second growing season after seeding. Alflfa will do well on the more moist sites but is highly palatable to deer, which can pose a traffic hazard. This leaves cicer milkvetch as the only legume which one might seed in addition to white clover. The seedling vigor of milkvetch is poor, but this species spreads by sending out shoots, and a thin initial stand can thicken considerably.

C. Mulching

Straw or grass hay applied at the rate of 4,500 kg/ha (4,000 lb/acre) is a better mulch for seedling establishment and erosion control than is wood fiber mulch. The State highway department is now using straw or hay mulches in preference to wood fiber. Introduction of unwanted seeds in straw or hay mulches has been a persistent problem, however.

D. Maintenance Fertilization

Even with topsoiling and an initial application of nitrogen, it is now evident (3 years later) that a deficiency of nitrogen is limiting the formation of an erosion-retarding cover of living plants and dead litter on some of the slopes. An annual maintenance application of 66 kg/ha (60 lb/acre) of nitrogen (N) is suggested. Maintenance fertilization appears to be necessary, or the topsoil will be eroded.

IV. SOURCES OF INFORMATION

Agricultural Research Service, USDA, Fort Collins

Colorado Division of Wildlife
  Administrative Headquarters, Denver
  Research Unit, Fort Collins

Colorado Extension Service
  Jefferson County Agent, Golden
  Specialists in agronomy, forestry, horticulture, range and soils available in Fort Collins

Colorado State Forest Service
  District Office, Golden
  State Office, Fort Collins

Colorado State Geological Survey, Denver

Colorado State Highway Department, Denver

Colorado State University, Departments of Agronomy, Earth Resources, Forest Science, Horticulture, and Range Science, Fort Collins

Forest Service, USDA
Supervisor's Office, Arapahoe National Forest, Golden
Regional Office, Denver
Rocky Mountain Experiment Station, Fort Collins

Geological Survey, USDI, Denver

Soil Conservation Service, USDA
Work Unit Office, Jefferson County
State Office, Denver

Note: Many landscaping, nursery and seed-supplying firms are located in the Denver area. In addition, there are many private environmental consulting firms and individuals available who work out of Denver and surrounding communities.

V. ADDITIONAL REFERENCES

Berg, W. A., J. A. Brown, and R. L. Cuany, Co-chairman, Proceedings, Workshop on Revegetation of High-Altitude Disturbed Lands, Colorado State University Natural Resources Center, Information Series No. 10, 87 pages (1974).

Hull, A. C., D. F. Hervey, C. W. Doran, and W. J. McGinnies, "Seeding Colorado Range Lands," Colorado State University Experiment Station, Bulletin No. 498-S, 46 pages (1963).

Marr, J. W., "Ecosystems on the East Slope of the Front Range in Colorado," University of Colorado Study Series in Biology No. 8, 133 pages (1961).

McGinnies, W. J., D. F. Hervey, J. A. Downs, and A. C. Everson, "A Summary of Range Grass Seeding Trials in Colorado," Colorado State University Experiment Station, Bulletin No. 73, 81 pages (1963).

TEXAS

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TEXAS--DEMONSTRATION AREA NUMBER 5

ROAD CUT IN EASTERN TEXAS

Summary

A strongly acid Weches Formation rich in pyrite, on a deep road cut in northeastern Texas, was topsoiled and planted to bermuda grass. A mulch sod was used. This material is obtained by scooping soil and grass to a depth of 6 in. and applying this mixture. Most of the original planting in 1964 had failed by 1967 because of very strong acidity created by the oxidation of the pyrite into sulfuric acid. Backfilling topsoil to a depth of 20 cm (8 in.) did not correct the problem. Variable rates of ground limestone up to 112 mt/ha (50 tons/acre) were applied and again cut slope was planted to bermuda grass. One year after applying lime, soil pH values varied from 2.9 to 5.8 throughout the plant bed, and did not reflect the amounts of lime added because of the natural variation in the amount of pyrite. Two years after applying lime, the stand of bermuda grass varied from good to dead; where dead, the soil at a depth of 6 to 9 in. had a pH of 2.7--as strongly acid as vinegar.

I. INTRODUCTION

The Weches Formation consists of semisolid marine deposits that lie between the Sparta Sands Formation above and the Queen City Sands Formation beneath. All three formations belong to the Claiborne Group. Outcrops of the Weches Formation have been reported in at least 30 counties in northeastern and south central Texas (Figures 39 and 40). Similar formations have been found also in Arkansas, Louisiana, Mississippi and Alabama.

Variations in the appearance, chemical composition, and physical nature of materials in the Weches Formation are common. The limits of the variations, however, are within these bounds:

1. A brick-red soil that has developed from surface weathering of glauconite.

2. Glauconite beds of relatively unweathered green fine-grained materials rich in marine fossils.

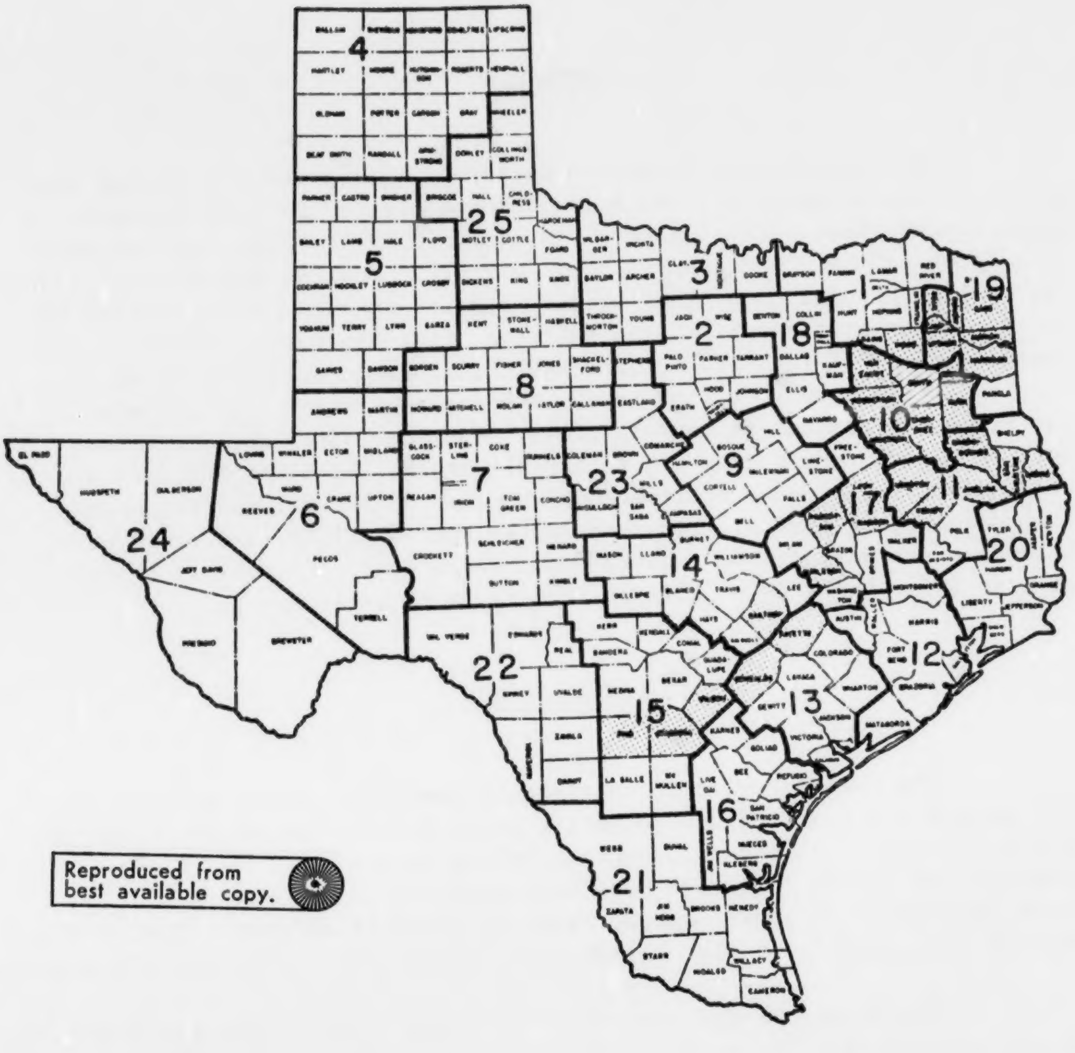
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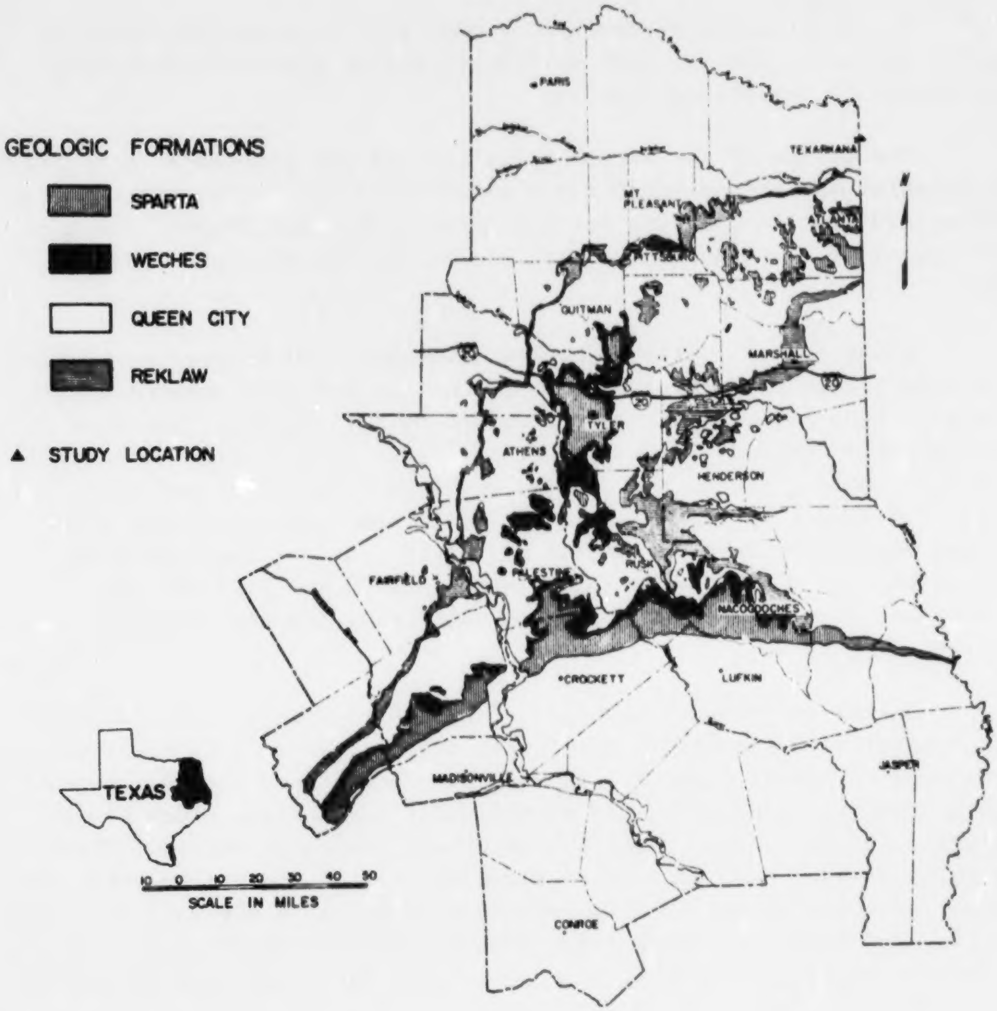
Figure 39 - Smith County, Texas, Where the Demonstration Site of Weches Formation is Located. In 30 counties in Texas (shaded) the weches formation has been identified. The numbers represent the districts of the Texas Highway Department.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MARSHALL
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ATHENS
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CROCKETT
LUFKIN
JASPER
MADISONVILLE
CONROE
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10 0 10 20 30 40 50
SCALE IN MILES

Figure 40 - Distribution of the Outcrops of the Acid Weches Formation Just North of Tyler, Texas. Associated geologic formations are also shown (Courtesy of Wesley L. Miller).

3. Porous iron ore (limonite) formed from weathering of glauconite exists as erosion-resistance caps on hilltops.

4. Interbedded sandstones, sands, and clays with a dispersal of pyrite crystals, nodular iron carbonate, and an admixture of carbonaceous materials resembling lignite.

The extent of the Weches Formation and the problem of establishing vegetation has been studied for a distance of 153 km (95 miles) along Interstate 20 from Van, at the eastern edge of Van Zant County, eastward to the border of Texas and Louisiana, at the eastern edge of Henderson County.

Along this 95 miles of highway, the soil and underlying geologic materials were sampled on 37 cut slopes that had been unsuccessfully vegetated. Lime requirement was determined on all samples. All soil materials tested needed lime in amounts from 0.4 to 5.2 mt/ha (0.2 to 23 tons/acre). Only three of the samples had a pH between 5.3 and 5.9; whereas, the lowest pH was 2.5. It was noted that the cut slopes with the least vegetation were always the most acid. At one location 5 km (3 miles) east of the interchange of Interstate 20 and U.S. 69, the acid drainage from the Weches Formation was dissolving the concrete drains.

Marine sedimentary materials that are rich in sulfur, iron sulfide, or other acid-generating substances are sources of soil acidity when exposed to the atmosphere. In many instances, they provide an environment that is unfavorable for establishing vegetation. Such conditions exist in the Weches Formation, which are marine in origin. Similar situations have been documented along the world's coastal marshlands. A highway or a buried pipeline in such areas exposes marshy soil to cycles of wetting and drying; the resulting chemical and bacteriological oxidation results in a very strongly acid soil. The soils are sometime designated as acid sulfate clays or cat clays.

A. Demonstration Area

Demonstration Area Number 5 includes all outcrops and all road cuts that expose the Weches Formation. This material, upon weathering, becomes so acid that it qualifies as nearly sterile because of high acidity.

B. Demonstration Site

The Weches Formation demonstration site is located on a cut slope along Interstate 20, 6 km (4 miles) east of the interchange with U.S. 69 and 16 km (10 miles) north of the city of Tyler, Smith County, Texas.

The highway road cut was 15 m (50 ft) in height and was finished to a grade of 4:1. Two terraces for water diversion were established on the approximate contour along the slopes (Figure 41).

At the site, seven different layers were described, sampled, and studied separately.[1/]

The site was selected because the bermuda grass mulch sod that was established on the slope in 1964 had failed by 1967, except for that section occurring between the original soil surface and the upper terrace (Figure 42).

The climate of the demonstration area is characterized by a mean annual temperature of 20°C (66°F), a mean annual precipitation of 114 cm (45 in.), a frost-free season of 252 days, and a mean annual range of relative humidity of 84 and 56% at 6 a.m. and 6 p.m., respectively. In brief, the climate is warm and humid with adequate and well-distributed rainfall--an ideal climate for bermuda grass and for almost any other vegetation that does not require a cool season to break its dormancy.

C. Weches Formation Description

The Weches Formation is a marine sedimentary deposit consisting of impure glauconite (a potassium iron silicate), clay and sand. The average width of the formation's outcrops varies from 9 to 46 m (30 to 150 ft). A vertical section of the Weches Formation may be seen in Figure 43.

[1/] Miller, W. H., "Formation of Free Acid in Soil Materials Exposed by Excavation for Highways in East Texas," thesis submitted to the Graduate College of Texas A&M University in partial fulfillment of the requirement for the Degree of Master of Science, 72 pages, August 1969.

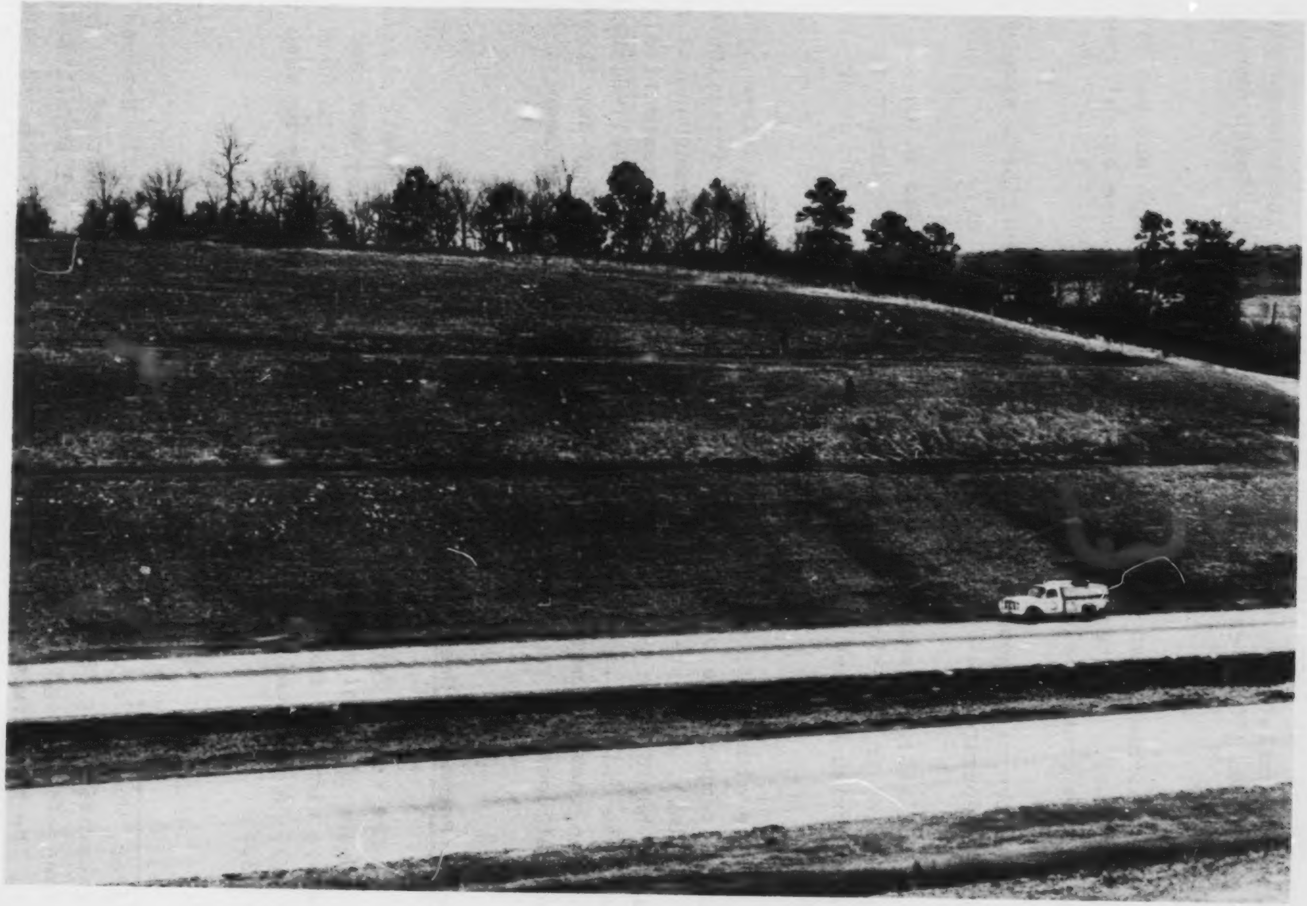


Figure 41 - The Demonstration Site in Eastern Texas, Showing the Two Diversion Terraces
(Courtesy of W. L. Miller, Texas A&M University)

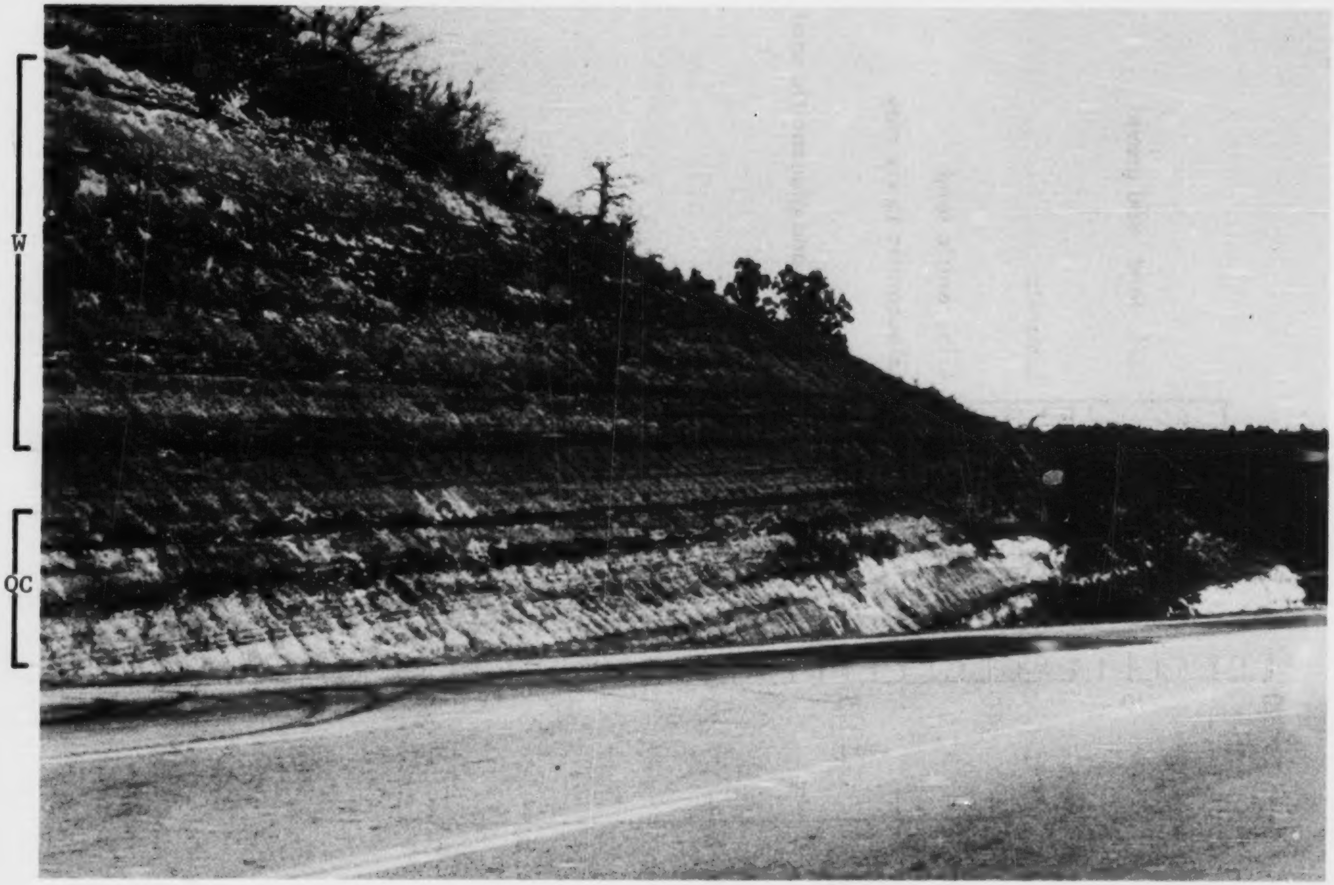
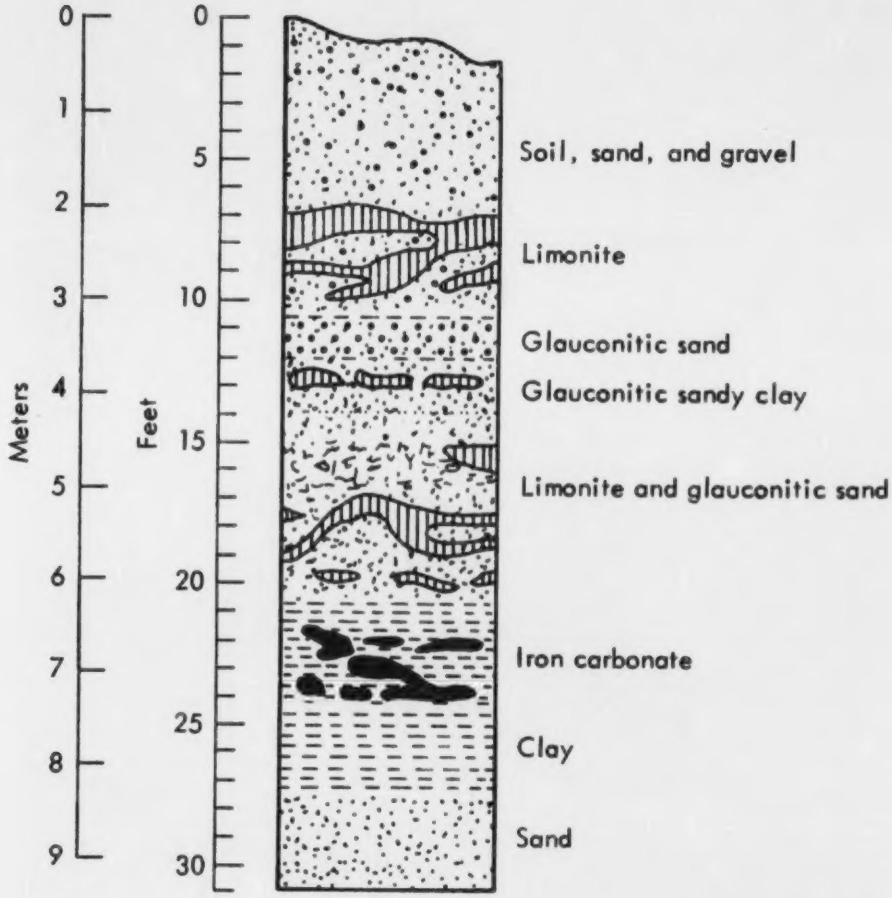


Figure 42 - Cut Slope Along the East Side of U.S. Highway 69, Approximately 20 Miles North of Tyler, Texas, Exposing the Glauconite and Ironstone Layers of the Weches Formation and the Gray Cross-Bedded Sands and Dark Carbonaceous Shales of the Queen City Formation (W = Weches Formation; QC = Queen City Formation) (Courtesy of W. L. Miller, Texas A&M University)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Soil, sand, and gravel
Limonite
Glauconitic sand
Glauconitic sandy clay
Limonite and glauconitic sand
Iron carbonate
Clay
Sand

Figure 43 - Vertical Section Showing Occurrence of Glauconite and Iron Ore in Weches Formation in Cass County

Although it may vary, glauconite in the Weches Formation has an approximate composition of:[1]

Element	Approximate Composition (%)
Silica (SiO_2)	25
Iron (FeO, Fe_2O_3)	20
Aluminum (Al_2O_3)	12
Calcium (CaO)	8
Magnesium (MgO)	2.5
Potassium (K_2O)	1.8
Phosphorus (P_2O_5)	1.3
Sodium (Na_2O)	1.1

Pyrite (FeS_2), known as fool's gold, was identified in most of the samples of materials from the cut slope. To demonstrate that pyrite existed in most of the samples and that weathering of pyrite produced more exchangeable acidity and a lowering of pH, the soil materials were subjected to a 21-week wetting-and-drying oxidation regime to simulate weathering, and then the changes in pH, water soluble sulfate-sulfur, and exchangeable acidity were determined. The conclusion was that many of the pyrite crystals that were intermixed throughout nearly all geologic sediments exposed on the cut slope were changed by chemical and bacteriological oxidation from iron sulfide (FeS_2) to sulfates (reported as sulfate-sulfur) during the 21-day laboratory wet-dry cycles. The pH of the sediments was also lowered. The correlation between the amount of sulfate-sulfur (SO_4-S) and the exchangeable acidity of $r = 0.98$ is a nearly perfect correlation (Figure 44).

II. ACIDITY AND PLANT GROWTH

Strongly acid soils are not favorable for the growth of plants for one or more of these reasons:

1. Hydrogen toxicity (below pH 4.0);
2. Aluminum toxicity;

---

[1] Sellards, E. H., W. S. Adkins, and F. B. Plummer, "Geology of Texas, Vol. I, Stratiography," The University of Texas, Bulletin No. 3232, 1,007 pages (1932).

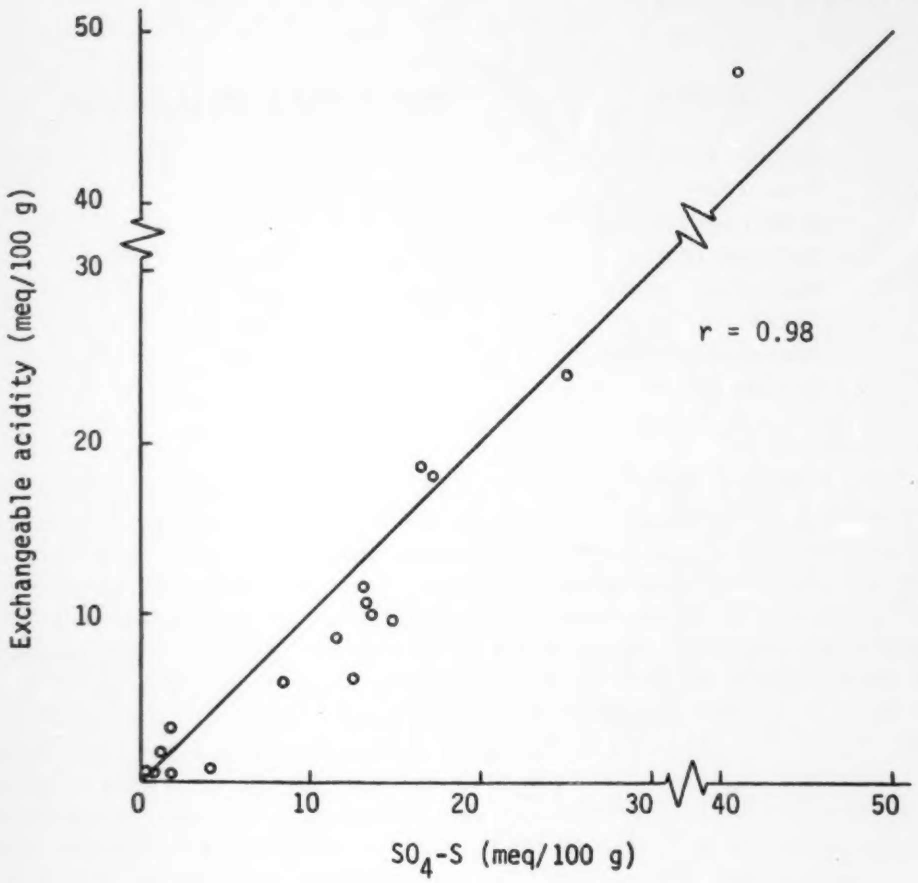


Figure 44 - Relationship of Increases in Water Soluble SO_4-S and Exchangeable Acidity Upon Oxidation of Soil Material From the Selected Cut Slope by Alternately Wetting and Drying the Samples in the Laboratory for a 21-Week Period. The r = 0.98 means a correlation coefficienct of 0.98 and is interpreted as excellent correlation between exchangeable acidity and the amount of sulfate-sulfur present in the soil.

3. Manganese toxicity;

4. Calcium deficiency;

5. Magnesium deficiency; and

6. Molybdenum deficiency.

With mineral soils, the following generalizations are accepted as valid assumptions:

1. When the soil pH is above 8.2, there is a strong indication that exchangeable sodium is present.

2. When the soil pH is between 7.8 and 8.2, the presence of calcium carbonate is indicated.

3. A pH below 5.5 suggests the presence of exchangeable trivalent aluminum.

4. A pH less than 4.0 indicates the presence of free acids as from the oxidation of sulfur or sulfides in the soil, as is true on this demonstration site Number 5.

When a soil is too acid for satisfactory plant growth, lime is usually applied to ameliorate the physiological conditions. The most common liming materials are ground natural limestones, the chemical composition of which varies from more than 90% calcium carbonate to dolometic limestone which may be about 55% calcium carbonate and 35% magnesium carbonate. On a pure basis, it takes only 25 kg (56 lb) of calcium oxide (CaO) or 34 kg (74 lb) of calcium hydroxide ($CaOH_2$) to neutralize as much soil acidity as 45 kg (100 lb) of calcium carbonate ($CaCO_3$). Since the oxides and hydroxides are made by burning natural limestones, the former are always higher in price except when the materials must be shipped long distances.

III. LIME REQUIREMENT

Since the soil pH determinations are rapid, they have been used as an indication of the lime requirement. The pH readings, however, are a measure only of the intensity of acidity and not the ion exchange capacity factor. For example, a sandy soil with a pH of 5.0 may have a true lime requirement of 4.5 mt/ha (2 tons/acre) to raise the pH to 6.5, in contrast to a clay soil with the same pH but with a lime requirement of 13 mt/ha (6 tons/acre). The explanation is that at the same pH, a clay soil has more exchangeable acidity to be replaced by calcium or magnesium in the lime.

Laboratory methods for determining lime requirement as a capacity factor of soil acidity include: (a) titrating or equilibrating the soil with a base, and (b) leaching the soil with a buffer solution, followed by analyzing the leachate for the amount of base retained by the soil. Because it is faster and often more accurate, the buffer method of determining lime requirement has gained wider acceptance.

The true lime requirement of the weathering products of the Weches Formation, however, cannot be determined by any of the foregoing techniques. The reason is that the weathering of sulfide, including chemical and biological oxidation, is a continuing process; the end product of which is sulfuric acid. The logical solution is to determine lime requirement by the buffer techniques, add an additional amount of lime as an "interpretive factor," then add more lime, periodically, to maintain vigor of established vegetation.

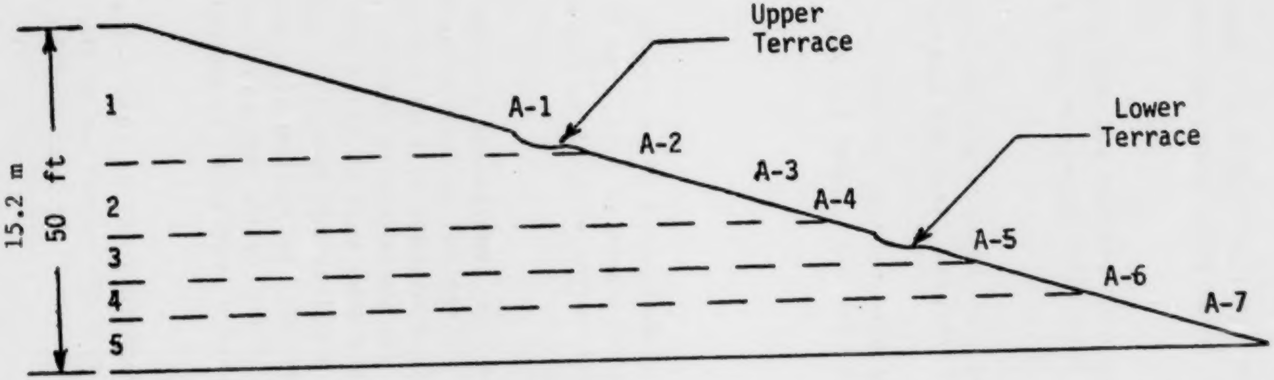
Such a system was applied in Louisiana on similar soil and geologic materials on cut slopes of the same Interstate 20.1/ With an original pH of 2.6, 18 mt (20 tons) of limestone per acre were applied and vegetation was successfully established. Approximately 5 mt (5 tons) of lime every 5 years was recommended for maintenance of the cover; however, at least annual on-site inspections should be made to determine the validity of the recommendation.

IV. DETAILS OF DEMONSTRATION SITE

A. Introduction

The demonstration site selected for discussion in this manual is a south-facing cut slope (Figure 41). Seven sampling sites (A-1 to A-7) involving five soil or geologic layers (numbered 1 to 5) were recognized and described as follows (from upper to lower slopes (Figure 45)).

1/ Grafton, B. F., "Vegetative Cover Study for Problem Soils," State Project No. 736-00-71, Louisiana Polytechnic Institute Division of Agriculture and Forestry Research, Ruston, Louisiana, 26 pages (1968).



Description of Soil or Geologic Layers

1 Reddish loams and sandy clay loams with reddish yellow mottling, with several ferruginous sandstone layers.

2 Dark olive green to dark olive gray clays and clay loams, with several ironstone layers and some glauconite.

3 Carbonaceous and pyritic bed occurring in dark olive green to dark olive gray clays and clay loams.

4 Carbonaceous, dark olive gray to dark gray clays and clay loams.

5 Light gray to light brownish gray silt loams and very fine sandy loams.

Figure 45 - Schematic (not to scale) Cross Section of the Selected Cut Slope Used for This Study Showing the Approximate Location of the Two Interception Terraces and Sampling Sites A-1 Through A-7.

Soil Material No. 1 - Sampling Site A-1; all of the area above the upper terrace. Reddish loams and sandy clay loams, with several layers of sandstone high in iron. This includes the surface 2 m (6 ft) of the Lakeland and Darco soil series.

Soil Material No. 2 - Sampling Sites A-2 and A-3. Dark olive green to dark olive gray clays and clay loams with layers of ironstone and glauconite.

Soil Material No. 3 - Sampling area between A-4 and A-5. Iron pyrite and lignite-like (carbonaceous) dark olive green to dark olive gray clays and clay loams.

Soil Material No. 4 - Sampling area between A-5 and A-6. Lignite-like (carbonaceous) dark olive gray to dark gray clays and clay loams.

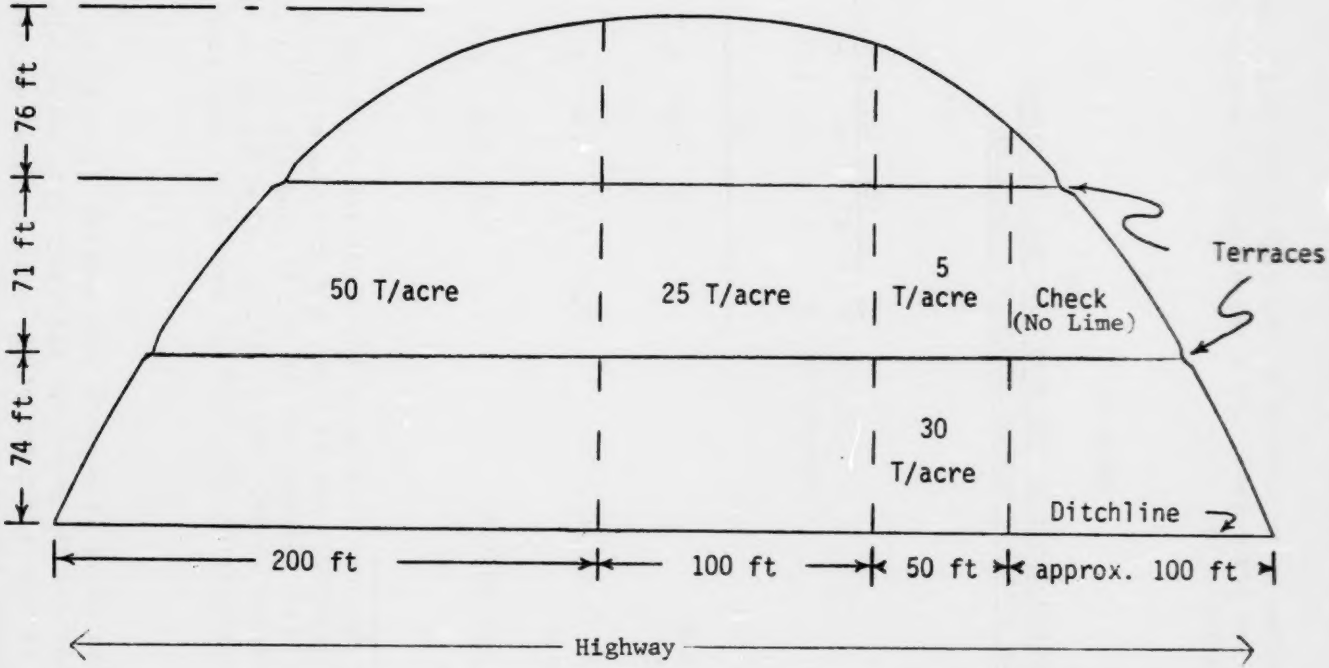
Soil Material No. 5 - Sampling area between A-6 and A-7 (bottom of slope). Light gray to light brownish gray silt loams and very fine sandy loams.

B. Lime Test Plots

The Texas Highway Department established a 25-cm (10-in.) soil mulch sod of bermuda grass on the entire cut slope in 1964. By 1967 the vegetation had died except on the original weathered soil at the top of the slope to a depth of about 2 m (6 ft).

To obtain the approximate gross lime requirement for the demonstration plots, exchangeable acidity was determined by potentiometric titration to pH 5.6 with sodium hydroxide in a mixture of soil and one normal potassium chloride solution. The values for exchangeable acidity ranged from zero for the added topsoil to slightly more than 45 mt/ha (20 tons/acre). For results within a year, field applications should be multiplied by a factor of two or three. For this reason, the maximum lime rate was established at 112 mt/ha (50 tons/acre). Other rates were arbitrarily set at 67, 56, 11 and 0 mt/ha (30, 25, 5 and 0 tons/acre) to provide additional information.

All applications of lime were made in April of 1968 and extended from the base to the crest of the slope, with the exception of the 11- and 67-mt (5- and 30-ton) rates (Figure 46). A rototiller was used to mix the


76 ft
71 ft
74 ft
50 T/acre
25 T/acre
5 T/acre
Check (No Lime)
30 T/acre
Terraces
Ditchline
200 ft
100 ft
50 ft
approx. 100 ft
Highway

feet	50	71	74	76	100	200
meters	15	22	22.5	23	30.5	61

tons/acre	5	25	30	50
metric tons/hectare	11	56	67	112

Figure 46 - Locations and Approximate Dimensions Along the Face of the Slope for the Various Rates of Calcitic Lime Applied on the Selected South-Facing Cut Slope.

lime with the soil to a depth of approximately 20 cm (8 in.) and then a bermuda grass mulch sod mixed with a reddish-brown fine sandy loam soil was placed over the entire surface of the slope.

One year after establishment of the vegetative cover, the pH of various soil layers was determined, and a representative portion of the data is portrayed in Table 13.

TABLE 13

pH OF SELECTED PLOTS ON THE NORTH-FACING CUT SLOPE ON MARCH 1969, 12 MONTHS AFTER APPLYING LIME

	Lime Applied				
mt/ha	0	11	56	67	112
tons/acre	0	5	25	30	50
Site	pH				
Bermuda Grass Mulch Sod on Moved-In Topsoil	4.7	4.5	5.0	4.7	5.8
Original Soil Material in Which Lime was Incorporated	3.8	4.2	3.4	4.3	5.5
Original Undisturbed and Unlined Cut Slope Material	3.2	3.3	2.8	2.9	3.3

Note: Data are from the lower-middle of the slope for the 0 and 11 mt/ha (0 and 5 tons/acre) rates of lime; and from the adjoining upper part of the lower section for the 56, 67, and 112 mt/ha (25, 30, and 50 tons/acre) rates. The 0, 11, and 67 mt/ha (0, 5, and 30 tons/acre) application rates did not extend the full length of the slope.

The pH of the moved-in topsoil plus bermuda grass mulch sod varied from 4.5 to 5.8; and the grass was satisfactorily established on all plots regardless of lime treatment of the soil material beneath. The depth of the moved-in topsoil varied from 18 to 38 cm (7 to 15 in.).

Soil material in which lime was incorporated had a pH range of 3.4 for the 56 mt/ha (25 tons/acre) rate to 5.5 for the 112 mt/ha (50 tons/acre) rate of ground limestone application. Beneath this layer, the original soil material had a range in pH of 2.8 to 3.3. It should be mentioned that the materials exposed on the slope did not change pH directly in proportion to the rate of lime applied as is usual on cropland soils because of the variation in content of acid-producing pyrite crystals.

As of March 1969, 1 year after establishing the lime test on the slope, the results of the total project were summarized as follows:

1. Topsoil which was hauled in by the Texas Highway Department in 1964, when the first bermuda grass sod mulch was established (but failed), plus that provided during the second planting made following the lime test, ranged from 18 to 38 cm (7 to 15 in.) in thickness.

2. In most instances the lime in the test plots was incorporated in the hauled-in topsoil rather than mixed with the geologic material on the face of the cut slope.

3. Bermuda grass roots were growing equally well whether in limed hauled-in topsoil or in limed natural cut slope material.

4. Bermuda grass roots never penetrated into the unlimed slope surface soil material.

The conclusions from this and other research results are that a satisfactory alternative to hauled-in topsoil is to make "topsoil" by carefully following recommendations from physical and chemical tests.

In many places the bermuda grass roots formed a flat mat at the junction between the hauled-in topsoil and the unlimed slope surface soil material. The most plausible explanation is that the untreated slope surface is an unfavorable medium for bermuda grass roots because of toxicity of hydrogen and/or aluminum or because of a deficiency of calcium, magnesium, and/or molybdenum. Another explanation may be because of incipient hardening of the slope surface due to weathering.

Two years after applying lime on the slope (summer 1970), soil pH had decreased from 4.2 to 3.2 where 11 mt/ha (5 tons/acre) of lime had been applied and the well-established bermuda grass was dead. Even the area where 112 mt/ha (50 tons/acre) of lime had been spread, the bermuda grass was variable from dead to good. In spots where the stand of bermuda grass was good, the pH of the surface 15 cm (6 in.) of soil was 6.4 and for the 15 to 23 cm (6 to 9 in.) depth below, was 5.8. Where the bermuda grass had died, even though 112 mt/ha (50 tons/acre) of lime had been applied, the surface 15 cm (6 in.) of soil had a pH of 5.2, whereas the original soil material beneath, at a 15 to 23 cm (6 to 9 in.) depth, had a pH of 2.7. The death of the bermuda grass was attributed to the low pH of 2.7 at the 15 to 23 cm (6 to 9 in.) in depth. (A soil pH of 2.7 has approximately the acidity of pure vinegar.)

V. SOURCES OF ASSISTANCE

Association of Texas Soil and Water
Conservation Districts

President
426 Fifth Street
Sealy, Texas 77474
713-885-3598

Vice President
Box 95
Cherokee, Texas 76832
915-622-4227

Secretary
Route 2, Box 214
Lubbock, Texas 79415
806-762-8697

Bureau of Economic Geology
University Station, Box X
Austin, Texas 78712

Environmental Protection Agency
Region VI
Suite 1100, 1600 Patterson Street
Dallas, Texas 75201

Soil Conservation Service
P.O. Box 648
Temple, Texas 76501

State Department of Agriculture
P.O. Box 12847, Capitol Station
Austin, Texas 78711

Texas A&M University
College Station, Texas 77843

VI. ADDITIONAL REFERENCES

Bieber, G. L., C. Y. Ward, and S. D. Attwell, "Establishment of Vegetation," Vol. I, Agronomy State Study No. 11, Agricultural Experiment Station, Mississippi State University, State College, Mississippi (1965).

Donahue, R. L., J. C. Shickluna, and L. S. Robertson, Soils: An Introduction to Soils and Plant Growth, 3rd Ed., Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 587 pages, pp. 52-67 (1971).

Edelman, C. H., and J. M. van Staveren, "Marsh Soils in the United States and in the Netherlands," Journal of Soil and Conservation, 13:5-17 (1958).

Fleming, J. F., and L. T. Alexander, "Sulfur Acidity in South Carolina Tidal Marsh Soils," Soil Scientist Society of American Proceedings, 25:94-95 (1961).

Grafton, B. F., "Vegetative Cover Study for Problem Soils," State Project No. 736-00-71, Louisiana Polytechnic Institute Division of Agriculture and Forestry Research, Ruston, Louisiana, 26 pages (1968).

Grass, L. B., V. S. Aronovici, and D. C. Muchl, "Some Chemical Characteristics of Submerged and Reclaimed Sediments of the San Francisco Bay System," Soil Scientist Society of American Proceedings, 26:435-455 (1962).

Kamrath, E. J., and C. D. Foy, "Lime-Fertilizer-Plant Interactions in Acid Soils," In: Fertilizer Technology and Use, 2nd Ed., Soil Scientist Society of America, Inc., Madison, Wisconsion, 611 pages, pp. 105-151 (1971).

McCully, W. G., W. J. Bowmer, and J. L. Stubbendieck, "Problems in Establishing or Maintaining Vegetation on Roadsides," Research Report 142-1, Texas Transportation Institute, Texas A&M University, 18 pages (1970).

McCully, W. G., and J. L. Stubbendieck, "Establishment and Management of Roadside Vegetation, 1971," Research Report 142-3, Texas Transportation Institute, Texas A&M University, 12 pages (1972).

McLean, E. O., "Testing Soils for pH and Lime Requirement," In: Soil Testing and Plant Analysis, Soil Scientist Society of America, Inc., Madison, Wisconsin, 491 pages, pp. 77-95 (1973).

Miller, W. L., "Formation of Free Acid in Soil Materials Exposed by Excavation for Highways in East Texas," a thesis submitted to the Graduate College of Texas A&M University in partial fulfillment of the requirement for the degree of Master of Science, 72 pages, August 1969.

Moorman, F. R., "Acid Sulfate Soils (Cat Clays) of the Tropics," Soil Science, 95:271-275 (1963).

Sellards, E. H., W. S. Adkins, and F. B. Plummer, "Geology of Texas, Vol. I, Stratiography," The University of Texas, Bulletin No. 3232, 1,007 pages (1932).

MISSISSIPPI

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MISSISSIPPI--DEMONSTRATION AREA NUMBER 6

ROADSIDE VEGETATION FOR STABILIZATION

Summary

Successful roadside stabilization in Mississippi by vegetation is not as difficult as in some areas of equally low soil productivity. The semitropical and humid climate is conducive to plant growth, and fertilization can ameliorate low soil fertility. Two soil Great Groups in Mississippi are clay and productive; whereas, the other two more extensive Great Groups are fine sandy and less productive. Topsoiling is recommended on only a few soils because most soils are deep and can be made productive on the cut and fill surfaces by lime and fertilizers that are applied according to a soil nutrient test. Mulching with organic materials is recommended on all seedings, and the best rate per hectare (acre) is given for each material by month of application.

The moist, semitropical climate is favorable to the seeding of some species of grasses and clovers during any month of the year. The probability of successfully establishing grass and legume species in any month is given by regions in the State. Selected woody plants are also recommended for roadside stabilization. Experience with the proper use of jute net in lieu of an organic mulch is also documented.

I. INTRODUCTION

Mississippi is located in the central southern part of the Southern Region. The climate is semitropical and humid, with prevailing southerly winds. The soil is never frozen except in the northern part of the State, and then only for a few days at a time. The result is a constant hazard of soil erosion. The hill soils are mostly highly leached and not naturally productive. The high rainfall, totaling 127 to 165 cm (50 to 65 in.) a year, coupled with heavy thundershowers and an occasional tropical storm, make conditions favorable for high sediment yield. Heavy rainfall associated with tornadoes further adds to the hazard of soil erosion and sediment runoff.

Soils of relatively low productivity in Mississippi are classified primarily into two soil orders, each with a predominant Great Group. Table 14 presents these extensive Great Groups, their total areas, and percentages in the United States.

TABLE 14

PRINCIPAL SOILS OF LOW PRODUCTIVITY IN MISSISSIPPI AND THEIR EXTENT IN THE UNITED STATES[a]

Soil Order	Soil Great Group	Extent of Great Group in U.S.		
		km^2	miles^2	%
Alfisols	Fragiudalfs	100,080	38,640	1.09
Utisols	Paleudults	465,550	179,750	5.08
Total		565,630	218,390	6.17

---

[a] "Soils of the United States--Area Measurements," Soil Conservation Service (undated).

Fragiudalfs occur in southern, southwestern, and northwestern Mississippi where the topography is gently sloping to rolling. The soils are well drained, highly leached, not very fertile, and usually sandy on the surface. The report in Subsection VII on the use of jute net lining for a water channel is on Fragiudalfs.

Paleudults are the predominant soil Great Group in Mississippi and occur in the southern and eastern half of the State. They are gently rolling, highly leached, well drained, mostly light brown fine sandy and silty soils.

The general productivity level of the soils, topography, estimated hazard of sediment yield, and relative ease of establishing vegetation are as follows:

Fragiudalfs - Low productivity, rolling, high sediment yield, and difficult to establish vegetation.

Paleudults - Very low productivity, rolling, high sediment yield, difficult to establish vegetation.

Construction activities in Mississippi involve principally highways and roads. Highway and road construction and reconstruction during 1972 totaled 67,915 km (42,199 miles). Totals by class are presented as follows:[1]

Class	Total (km)	Total (miles)
Primary State Highways	1,442	896
Secondary Roads	3,930	2,442
Local Roads	62,543	38,861
Total	67,915	42,199

II. TOPSOILING

When the final grade surface is determined, by preconstruction borings, to consist of coarse sand, rock, gravel, or very fine clay, topsoil should be stripped from the site during construction activities and stockpiled. Ideally, this material should contain less than 80% sand and between 10 and 30% clay. Soils within this textural range are classified mostly as sandy loam, loam, silt loam, or sandy clay loam, depending on the silt content. Less desirable as a growing medium are all sand soils, most loamy sands, all silts, most clay loams, most silty clay loams, and all sandy clays, silty clays, and clay soils.

Topsoiling is not necessary when the underlying parent materials on the final grades are within the textural ranges specified for topsoil and at least 1 m (3 ft) deep.

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[1] "Highway Statistics, 1972," U.S. Department of Transportation, Federal Highway Administration, Tables SMB-2 and OMB (November 1973).

III. SITE PREPARATION

Cut and fill slopes should be established at a slope grade no steeper than 4:1. Such slopes permit standard farm and construction machinery to operate normally. The site should be disked to a depth of 10 to 15 cm (4 to 6 in.). Soils should be sampled for fertility testing to determine the lime and fertilizer needs.

Apply lime according to soil test and disk into the soil. Wait a few days and disk in the recommended fertilizers. Lime and fertilizer should not be in contact with each other before being applied to the soil because of the hazard of loss of nitrogen as ammonia.

IV. GRASSES AND LEGUMES

Because of the semitropical climate in Mississippi, there are seeding mixtures recommended for establishment during any season of the year, as itemized in Table 15. All species of grasses and legumes are propagated by seed. Bermuda grass can be seeded, but it is propagated best by plant parts (sprigs). Even here, however, to insure success, 11 kg/ha (10 lb/acre) of bermuda grass seed are recommended on top of the sprigs. The soil should be cultipacked after seeding to firm the seedbed.

Immediately after seeding, apply the mulch most suitable for the site (See Subsection VI and Section V-J).

Sprinkler irrigation of the seeds or sprigs is essential if rains are not sufficient to assure a satisfactory germination and growth. The first irrigation of 1.3 cm (1/2 in.) of water should be made soon after the mulch has been applied; this reduces splash erosion and soil crust formation. Until it rains, 3 mm (1/8 in.) of water should be applied daily until the seedlings or plants are well established. Establishment may take from 2 to 3 weeks (Figures 47, 48, and 49).

The probability of establishing a successful seeding of grasses or legumes on roadsides during any 1 month in the year, by regions in Mississippi, is portrayed in Table 16. In the table, a 0 means no chance of establishment and a 9+ means a chance of success of more than 90%.

TABLE 15

RECOMMENDED SEEDING MIXTURES FOR ROADSIDE VEGETATION IN MISSISSIPPI[a]

Species Combinations	Recommended Rates at Various Times of Seeding[b]								Remarks
	Spring		Summer		Fall		Winter		
	kg/ha	lb/acre	kg/ha	lb/acre	kg/ha	lb/acre	kg/ha	lb/acre	
Bahiagrass	34	30	34	30	-	-	-	-	Use Pensacola Bahiagrass in Southern, Wilmington in Northern, Mississippi
Annual Lespedeza	17	15	17	15	-	-	-	-	
Lespedeza Vergata	22	20	22	20	-	-	-	-	
Bahiagrass	34	30	34	30	-	-	-	-	Use State-Wide
Sericea (Interstate)	22	20	22	20	-	-	-	-	
Bahiagrass	34	30	34	30	34	30	34	30	Spring and Summer State-Wide; Fall and Winter South of I-20
Bermudagrass	17	15	17	15	17	15	17	15	
Crimson Clover	-	-	-	-	17	15	17	15	
Bahiagrass	-	-	-	-	34	30	34	30	Use North of I-20
Bermudagrass	-	-	-	-	17	15	17	15	
Tall Fescuegrass	-	-	-	-	34	30	34	30	
Crimson Clover	-	-	-	-	17	15	17	15	
Bermudagrass	17	15	17	15	-	-	-	-	State-Wide
Annual Lespedeza	17	15	17	15	-	-	-	-	
Lespedeza Vergata	22	20	22	20	-	-	-	-	
Bermudagrass (Sprigs)[c] (Bu)	90	80	90	80	134	120	134	120	Omit Fescue South of I-20
Crimson Clover (%)	-	-	-	-	17	15	17	15	
Tall Fescuegrass	-	-	-	-	22	20	22	20	
Bermudagrass (Sprigs)[c] (Bu)	90	80	90	80	134	120	134	120	Use - Southern 2/3 of State
Crimson Clover	-	-	-	-	17	15	17	15	
Bahiagrass	34	30	34	30	34	30	34	30	
Tall Fescuegrass	34	30	-	-	34	30	34	30	Use - Northern 1/2 of State
Annual Lespedeza	22	20	-	-	-	-	-	-	
Sericea Lespedeza	22	20	-	-	22	20	22	20	
Tall Fescuegrass	34	30	-	-	34	30	34	30	Use - North of I-20
Bermudagrass	17	15	-	-	17	15	17	15	
Crimson Clover	17	15	-	-	17	15	17	15	
Weeping Lovegrass	11	10	11	10	11	10	-	-	State-Wide
Sericea Lespedeza	22	20	22	20	22	20	-	-	
Weeping Lovegrass	11	10	11	10	-	-	-	-	State-Wide
Bahiagrass	34	30	34	30	-	-	-	-	
Weeping Lovegrass	11	10	-	-	11	10	-	-	State-Wide
Vetch (Reseeding)	28	25	-	-	28	25	-	-	
Weeping Lovegrass	11	10	17	15	-	-	-	-	Topseed Summer Planted Lovegrass with Crownvetch
Crownvetch	11	10	-	-	11	10	-	-	

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[a] "The ABC's of Roadside Vegetation - An Informal Guide for Planting and Establishing Permanent Roadside Vegetation," Research and Development Division, Mississippi State Highway Department in Cooperation with the Federal Highway Administration, U.S. Department of Transportation, 43 pages, April 1974.

[b] Rates of seeding are based on "Pure Live Seed." Inoculate all legume seed and treat all grass seeds with an approved disinfectant protectant.

[c] One sq yd of cultivated sod = 1 bushel of sprigs. Always add 11 kg/ha (10 lb/acre) of common bermudagrass seed per acre when planting sprigs regardless of season.

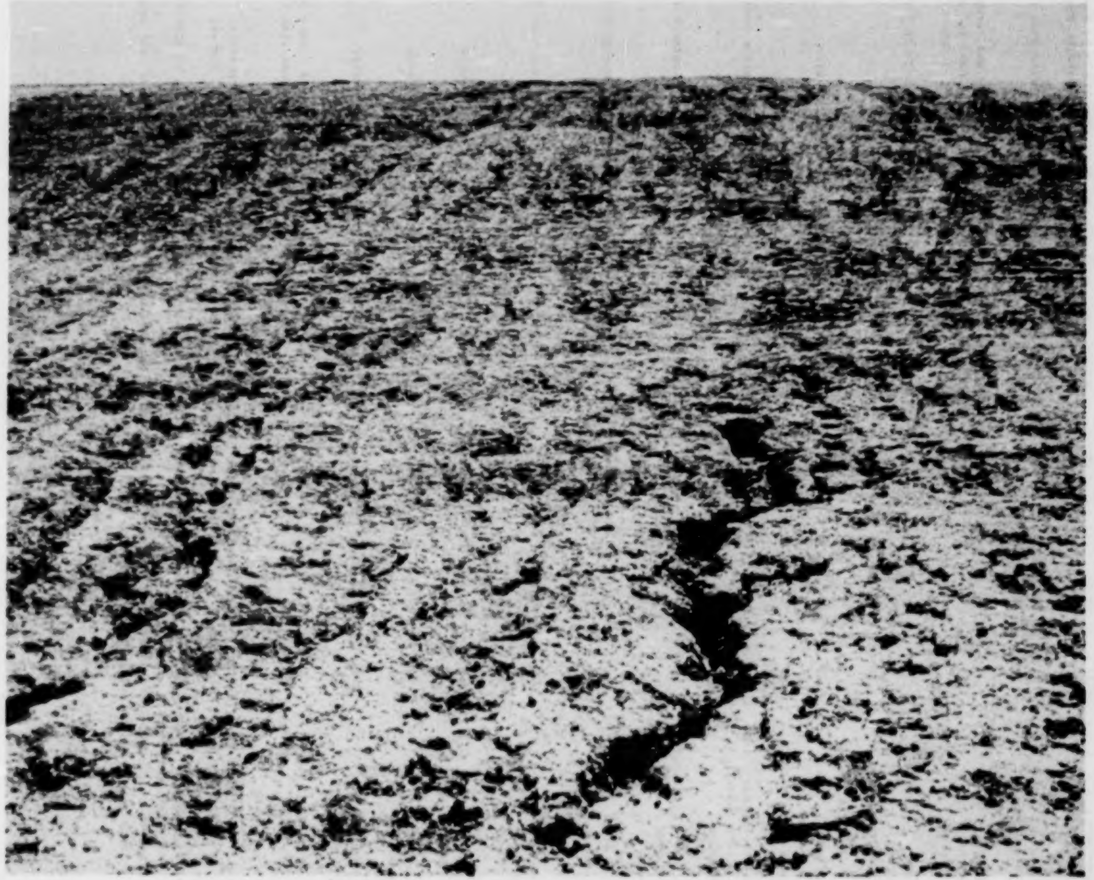

Figure 47 - Cut and Fill Slopes in Mississippi Should be Established at a Grade of 4:1 (14 degrees, 25%) or Less Because of the Semitropical Climate, High Rainfall, and Erodible Soils. This is a 3:1 slope and it has produced erosion sediments (see Figures 48 and 49).
(Courtesy of H. D. Palmertree)

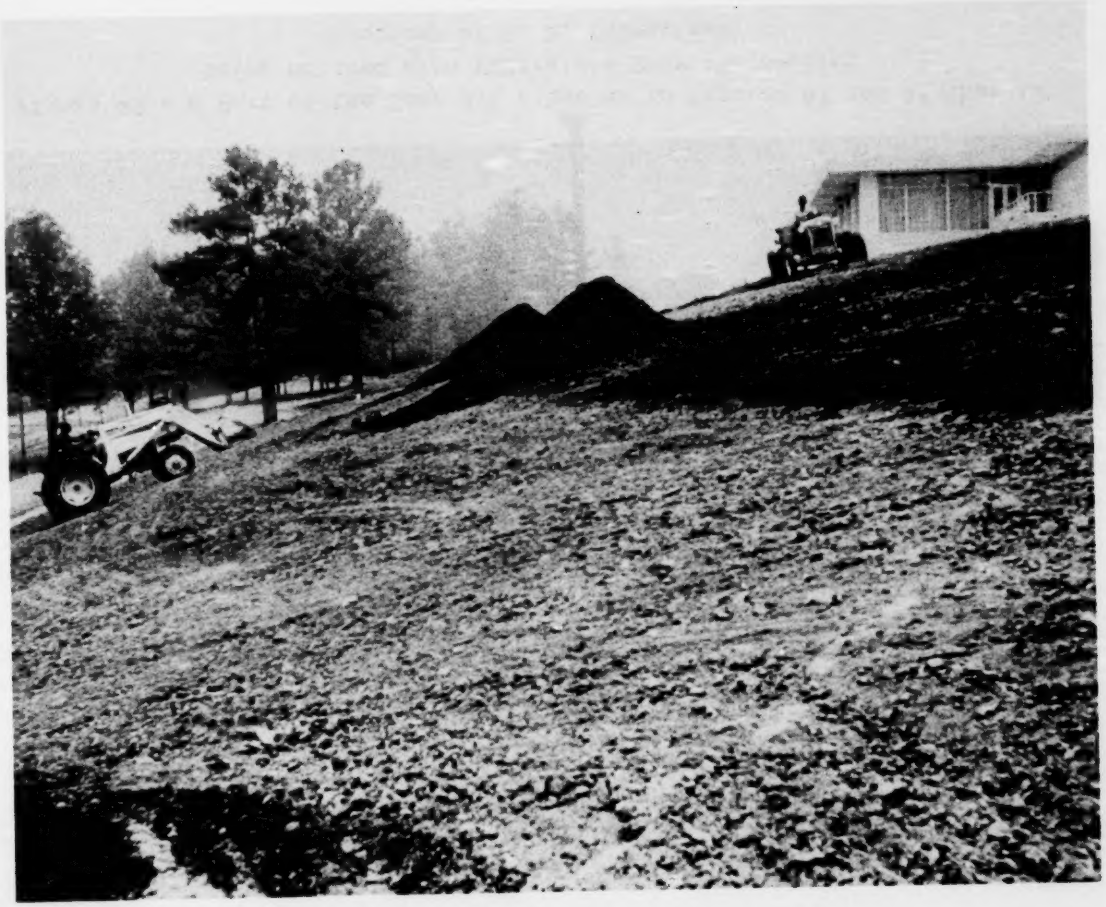

Figure 48 - A Part of the Same 3:1 Slope as in Figure 47 That is Being Topsoiled (Courtesy of H. D. Palmertree)

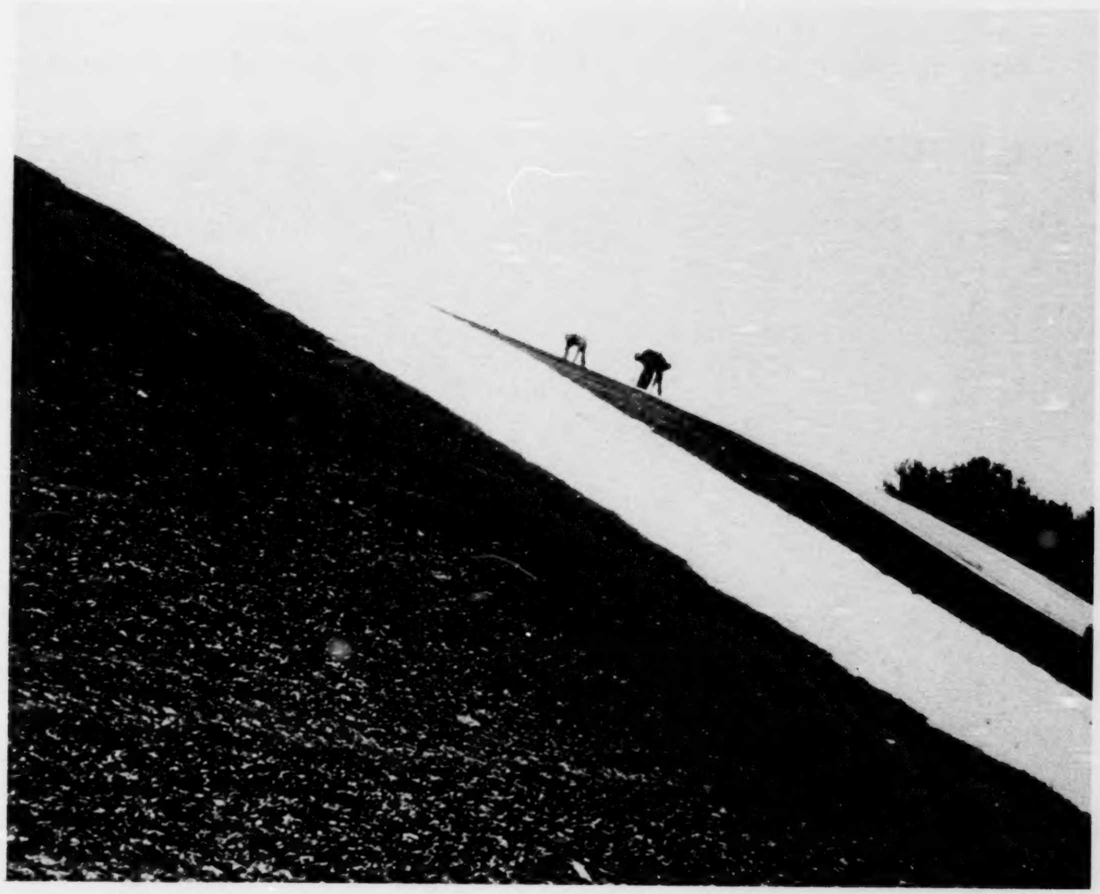

Figure 49 - A Part of the Same 3:1 Slope as in Figures 47 and 48 That is Being Mulched With Fiberglass Over the Seeding
(Courtesy of H. D. Palmertree)

TABLE 16

MONTHLY PROBABILITY FOR SUCCESSFUL ESTABLISHMENT OF RECOMMENDED SPECIES ON ROADSIDES IN MISSISSIPPI[a/]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
NORTH MISSISSIPPI												
Bahiagrass (Wilmington)	1	2	5	7	8	8	7	6	3	2	1	1
Bermuda Grass (Seed)	1	2	4	8	9+	7	6	5	2	1	1	1
Bermuda Grass (Sprigs)	3	3	4	9+	9+	8	8	8	6	4	2	2
Crimson Clover	2	2	3	1	0	0	0	4	9	8	5	4
Crownvetch	1	1	4	5	2	1	1	1	6	5	2	1
Annual Lespedeza	1	1	7	9	9+	5	2	1	0	0	0	0
Lespedeza Vergata	1	1	2	5	7	4	2	2	1	1	1	1
Sericea Lespedeza	1	1	3	7	8	6	3	3	2	2	1	1
Tall Fescuegrass	4	4	5	5	2	0	0	4	7	9	9	6
Weeping Lovegrass	1	1	4	9	9	8	7	7	4	2	2	2
CENTRAL MISSISSIPPI												
Bahiagrass (Pensacola)	2	3	6	8	9+	8	8	7	5	2	1	1
Bermuda Grass (Seed)	1	2	4	9	9+	8	7	7	2	1	1	1
Bermuda Grass (Sprigs)	3	3	5	9+	9+	8	8	8	6	4	2	2
Crimson Clover	3	3	2	1	0	0	0	2	9	9	5	4
Annual Lespedeza	1	1	5	9	9	4	2	1	0	0	0	0
Lespedeza Vergata	1	1	2	5	7	4	2	2	1	1	1	1
Sericea Lespedeza	1	1	4	9	8	6	3	3	3	2	1	1
Tall Fescuegrass	3	3	5	5	2	0	0	2	7	8	7	4
Weeping Lovegrass	1	1	5	9+	9+	8	7	7	4	2	2	2
SOUTH MISSISSIPPI												
Bahiagrass (Pensacola)	2	3	7	9+	9+	9+	9+	8	6	3	2	2
Bermuda Grass (Seed)	1	3	6	9	9	9	9	8	5	2	1	1
Bermuda Grass (Sprigs)	3	3	6	9+	9+	9+	9+	9+	9+	4	3	3
Crimson Clover	3	3	1	0	0	0	0	1	8	9	9	5
Annual Lespedeza	1	2	5	9	9	4	2	1	0	0	0	0
Lespedeza Vergata	1	1	3	7	6	3	2	2	1	1	1	1
Sericea Lespedeza	1	2	6	9	8	6	3	3	3	2	1	1
Weeping Lovegrass	2	2	5	9	9	9	9	9	7	2	2	2

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a/ "The ABC's of Roadside Vegetation--An Informal Guide for Planting and Establishing Permanent Roadside Vegetation," Research and Development Division, Mississippi State Highway Department, in cooperation with the Federal Highway Administration, U.S. Department of Transportation, 43 pages, April 1974.

Note: 0 = None, to 9+ = Over 90% chance of success.

V. WOODY PLANTS

Seeds of many woody plants may be sown on top of the legume and grass seeding, either before or after mulching. The most certain technique for assuring a satisfactory stand of trees or shrubs, however, is by planting small "liner" plants 30 to 46 cm (12 to 18 in.) tall. Most deciduous woody plants can be established by planting bare-root stock; whereas, evergreen plants must be planted with a soil ball. Often pot-grown plants offer the best assurance of successful establishment.

Fertilization of woody plants can be accomplished, according to recommended practice, by placing near the bottom of each planting hole one 10-g (1/3-oz) tablet of Agriform, analyzing 20-10-15 (N, P_2O_5, K_2O), or its equivalent.

The best dates for planting are 1 November to 15 March. Most woody plants should be on 1 to 2 m (3 to 5 ft) centers. As it is set out, each plant should be watered by soaking or by leaving a saucer-shaped depression around each plant and filling the depression several times as the water moves around the roots. If no soaking rains are received, add water to each plant about once a week for at least a month, and once a month for a year if rainfall is not adequate to maintain moist soil around the roots.

Some plants such as winter honeysuckle, multiflora rose, vanhouttei spirea, Reeves spirea, forsythia, and Chinese privet can be successfully established by stem cuttings. The cuttings for use on roadsides should be made 38 to 46 cm (15 to 18 in.) long from branches that have become fully dormant. They can be stored in moist burlap, sawdust, or sand or set out immediately after they are cut. The best planting date for stem cuttings is 15 November to 15 January. Before setting out, all leaves should be stripped, then the cuttings pushed, lower-end first, into the soil to a depth of 10 to 15 cm (4 to 6 in.), on 0.3-m (1-ft) centers.

VI. MULCHING

Various mulching materials have been tried with success in Mississippi. Mulches minimize fluctuations in soil temperature, reduce soil moisture losses, prevent erosion, inhibit weeds, and enhance the chances of successful establishment of vegetation.

1. Black polyethylene plastic has been used successfully to smother unwanted grasses and weeds between plantings of trees and shrubs. To reduce wind impacts and deterioration by ultraviolet rays from the sun, the black plastic should be covered with materials such as sawdust, pine needles, bark, woodchips, straw, or hay.

2. Bark, woodchips, or sawdust applied to a depth of 5 to 8 cm (2 to 3 in.) over new seedings of grasses and legumes, or seedings of trees and shrubs, or between plantings of shrubs and trees, have proved satisfactory.

3. Straw from wheat; oats; barley; rye, or rice, and hay from nearly any grasses or legumes, have all been used extensively and successfully over the State. The greatest disadvantage to the use of straw and especially of hay results from the weed seeds which they contain. An application of about 4.5 mt/ha (2 tons/acre) will make a covering of 5 to 8 cm (2 to 3 in.) over the soil surface. On windy areas or on steep slopes, straw can be held in place by using a special apparatus which applies hot asphalt to the straw as it comes from a blower. The usual rate of application of the asphalt preparation is 416 liters/mt (100 gal/ton) of straw.

4. Excelsior has also been used with success in Mississippi, especially when it is tacked with asphalt.

5. Wood cellulose fiber is another forest product that has been tried. It should be applied in a water slurry with a hydroseeder at a pressure of about 5.6 kg/cm^2 (80 lb/in.^{2}).

6. Mats made from fiberglass or jute have been successful when pinned to the soil with metal or wood stakes to prevent water from flowing under and eroding them. Mats are used most frequently in channels where water flows reach high volumes or high velocities and where vegetation is being established. The greatest disadvantage of the use of mats is their high cost.

A summary of the recommended mulch materials and the amount to be used per hectare (acre), as influenced by their season of use, is shown in Table 17.

From information presented in Table 17, it can be seen that an application of 3.4 to 4.5 mt/ha (1-1/2 to 2 tons/acre) of straw tacked with asphalt is recommended to protect plantings from April through October. To be effective during January, February, November, and December, however, requires 7 mt/ha (3 tons/acre) of straw. Hay is less effective than straw on a per-ton basis. Excelsior rates in relation to the recommended season of use are about the same as for straw; less asphalt, however, is required per ton of excelsior. Wood cellulose is recommended as effective only for the summer season.

VII. JUTE NET FOR CHANNEL LINING

A successful technique for the use of jute netting to retard erosion on constructed water channels while bermuda grass was being established from seed is documented as follows:[1]

During construction of the Country Club at Jackson, Mississippi, two water channels of lengths of 91.4 m (100 yd), and 182.8 m (200 yd), were reshaped by widening to 6.1 m (20 ft) and flattening of the side slopes.

According to a soil test, the soil was limed and fertilized, and these materials were incorporated in the soil separately with a disk to a depth of 7.6 cm (3 in.).

Bermuda grass seeds were broadcast on the soil surface and cultipacked. Immediately after seeding, a jute net 121.9 cm (48 in.) wide was placed over the seeded surface and stapled to the soil at intervals of 30.5 cm (1 ft). At the upper end of the channel, a trench 6 in. deep was dug across the ends of the jute netting were buried, to reduce the hazard of underwash. Sprinkler irrigation was used for 2 weeks to keep the net seed, and seedlings most until growth had become well established.

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[1] "The Use of Jute Net for Channel Lining," Department of Agronomy, Mississippi State University, State College, Mississippi (Unpublished) (1963).

TABLE 17

RECOMMENDED MULCH MATERIAL AND RATE PER ACRE AS INFLUENCED BY SEASON OF YEAR[a]

Mulch	mt/ha	tons/ acre	ℓ/mt	Asphalt gal/ton of Mulch	Season of Planting											
					Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Straw[b]	3.3	1.5	416	100	-	-	-	XX	XX	XX	XX	XX	XX	XX	-	-
Straw[b]	4.5	2	416	100	-	-	XX	XX	XX	XX	XX	XX	XX	XX	-	-
Straw[b]	6.7	3	416	100	XX	XX	-	-	-	-	-	-	-	-	XX	XX
Hay[b]	4.5	2	416	100	-	-	-	XX	XX	XX	XX	XX	XX	-	-	-
Hay[b]	6.7	3	416	100	-	-	XX	XX	XX	XX	XX	XX	XX	XX	-	-
Excelsior[b]	4.5	2	208	50	-	-	XX	XX	XX	XX	XX	XX	XX	-	-	-
Excelsior[b]	6.7	3	208	50	XX	XX	XX	-	-	-	-	-	-	-	XX	XX
Wood Cellulose[c]	1.1	1/2		NONE	-	-	-	XX	XX	XX	-	-	-	-	-	-
Wood Cellulose[c]	1.7	3/4		NONE	-	-	XX	XX	XX	XX	-	-	-	-	-	-

---

[a] "The ABC's of Roadside Vegetation--An Informal Guide for Planting and Establishing Permanent Roadside Vegetation," Research and Development Division, Mississippi State Highway Department, in Cooperation with the Federal Highway Administration, United States Department of Transportation, 43 pages, April 1974.

[b] Mulches applied with a straw blower with apparatus to apply hot asphalt to mulch as it leaves chute of wind tunnel.

[c] Applied in water slurry with a pumping apparatus capable of supplying 5.6 kg/cm^2 (80 lb/in.^{2} at orifice.

Germination and seedling establishment was completed within a period of 1 to 2 weeks, and stabilization of the channel was apparent at the end of 2 months. No mowing was done until 3 months after seeding. All areas were topdressed once each month with 120 kg/ha (100 lb/acre) of nitrogen (N) fertilizer. Although there was a slight amount of erosion before the bermuda grass seedlings were well established, at the end of 3 months the site was stabilized and no further evidence of erosion or siltation occurred.

Other research near Jackson, Mississippi, on a 4:1 cut slope compared the effectiveness of uniformly seeded bermuda grass, covered with three kinds of mulch. The mulch most effective in retarding erosion was straw, followed by fiberglass, then by wood fiber.[1/]

Nine years of research on vegetating water channels along highways, conducted by Mississippi State University, are summarized by these recommendations:

1. Soil test for lime and fertilizer needs. Most land-grant universities provide this service.

2. Prepare channel to desired contour and grade.

3. Apply lime and fertilizer according to a soil test and incorporate with a pulverizing disk.

4. Seed 33.6 kg/ha (30 lb/acre) of common bermuda grass.

5. Mulch with jute net or similar "blanket type" mulch. Careful installation is a necessity; if water flows under the jute net, erosion will occur and the seedings will probably be a failure.

6. Topdress every 2 months during the first growing season with 74 kg/ha (66 lb/acre) of nitrogen fertilizer.

7. Mowing should be done only as needed. A reel-type mower is more desirable than a rotary mower because of less damage to the mulch.

8. Watering until plant establishment will increase the rate of bermuda grass spread and contribute toward greater success.

[1/] "Stabilization of Roadsides with Bermudagrass," Department of Agronomy, Mississippi State University, State College, Mississippi (Unpublished) (1964).

VIII. MAINTENANCE

Because of the highly permeable and relatively sterile soils, high rainfall, and subtropical temperatures, grass seedings should be topdressed each spring with 224 kg/ha (200 lb/acre) of ammonium nitrate or its equivalent. For legumes, an application each spring of 336 kg/ha (300 lb/acre) of 0-20-20 fertilizer is recommended. A soil test before fertilizer application will determine if there should be any variation in the kinds or amounts of fertilizer.

At least twice a year, all roadside cuts, fills, medians, and channels should be inspected to correct any failures of slope or vegetation.

IX. SOURCES OF FURTHER INFORMATION

Chairman, State Soil and Water Conservation Committee
Stockville, Mississippi 39762
601-323-1482

Commissioner, Department of Agriculture and Commerce
P.O. Box 1609
Jackson, Mississippi 39205
601-354-6563

Department of Agronomy
Mississippi State University
State College, Mississippi 39762
601-325-4181

Director of Extension
Mississippi State University
State College, Mississippi 39762
601-325-4434

Director, Southern Forest Experiment Station
701 Loyola Avenue
New Orleans, Louisiana 70113
504-527-6787

President, Mississippi Association of Soil and Water
Conservation District Commissioners
Horn Lake, Mississippi 38637
601-393-2961

State Conservationist
Soil Conservation Service
Milner Building, Lamar and Pearl Streets
Box 610
Jackson, Mississippi 39205

State Forester, Forestry Commission
908 Robert E. Lee Building
Jackson, Mississippi 39201
601-354-7124

X. ADDITIONAL REFERENCES

"The ABC's of Roadside Vegetation--An Informal Guide for Planting and Establishing Permanent Roadside Vegetation," Research and Development Division, Mississippi Highway Department in cooperation with the Federal Highway Administration, U.S. Department of Transportation, 43 pages, April 1974.

"Critical Area Planting," Soil Conservation Service, Technical Guide, Section IV, Code 342, Jackson, Mississippi, 4 pages (1974).

Thompson, W. R., and H. D. Palmertree, "Mulches Improve New Turf Stands," *Weeds, Trees, and Turf*, 6:48-50 (1967).

WEST VIRGINIA

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WEST VIRGINIA--DEMONSTRATION AREA NUMBER 7

HIGHWAY REVEGETATION IN THE APPALACHIAN MOUNTAINS

Summary

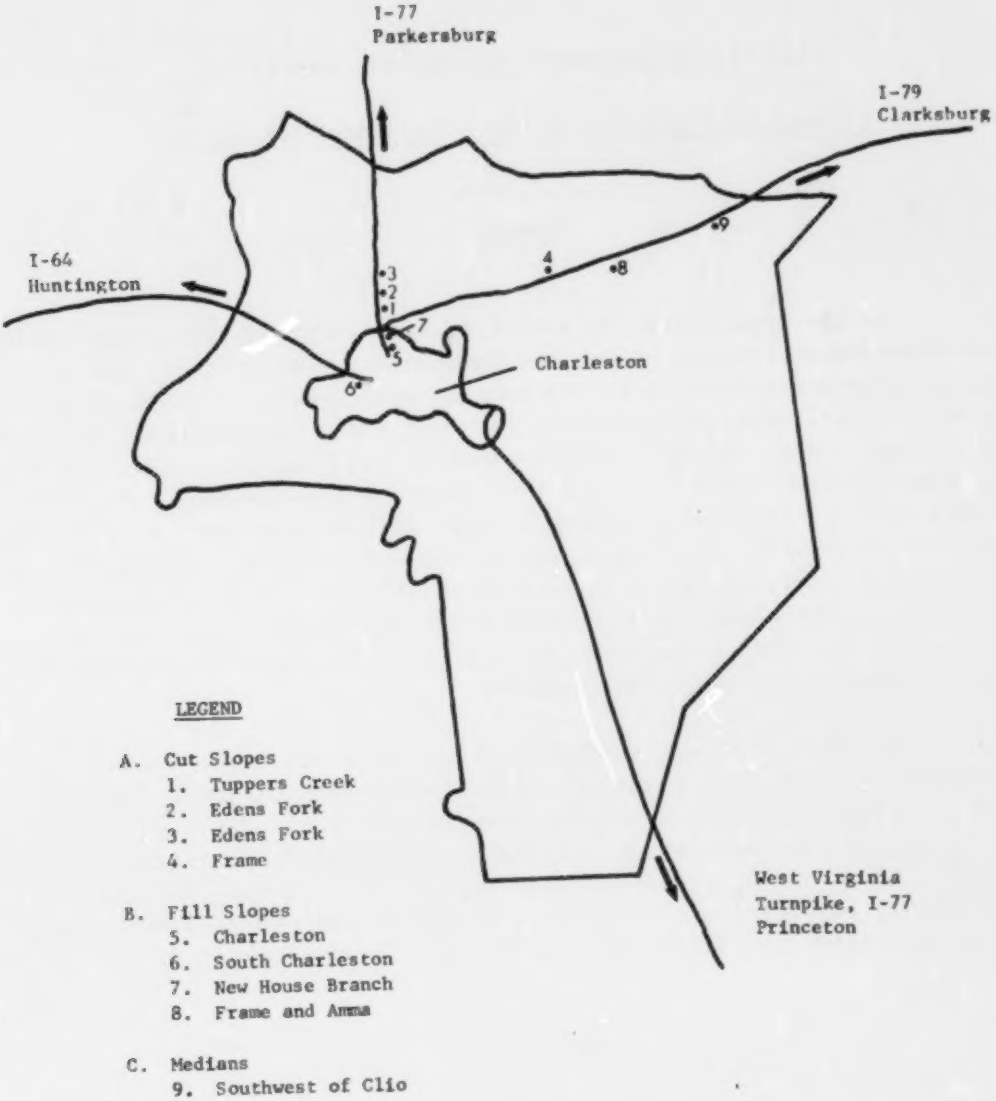
In the Appalachian Mountains of West Virginia, the stony soils, steep topography, intense summer thundershowers, cold winters, and alternate freezing and thawing make for a harsh environment in which to establish vegetation. Favorable factors for vegetation establishment are the high rainfall, high humidity, and absence of soil toxins. Soils are usually fine-textured and stony, low in nitrogen and phosphorus, and either strongly acid or strongly alkaline. Steep slopes of a grade of 1:1 should usually be stair-step and left rough graded. Cut and fill slopes should be left rough to facilitate seedling establishment. Seeding mixtures used include the cool-season plants--Kentucky-31 fescuegrass, creeping red fescuegrass, and annual ryegrass; as well as warm season plants--crownvetch, weeping lovegrass, and German millet.

A mulch of straw, woodchips, bark, or woodfiber cellulose is also used. Of the mulches tested, straw is superior for enhancing the rapid establishment of the perennial seedings. If the first seeding is thin, a second seeding and fertilizing is recommended. Selected shrubs and small trees are also a recommended option for highway roadside stabilization. In addition to the trees or shrubs, an overseeding at one-half of the normal seed rate plus mulching is also recommended.

I. INTRODUCTION

A. Location of Demonstration Areas

The specific demonstrations in the Appalachian Mountain Region are along converging Interstate Highways 77, 79, and 64 and Interchanges in Kanawha County (Figure 50). They are under various stages of construction in the vicinity of Charleston, the capital city of West Virginia. The elevation of the area varies from 174 to 804 m (542 to 2,650 ft) and is mostly steep and mountainous.


I-77
Parkersburg
I-79
Clarksburg
I-64
Huntington
3
2
1
7
5
6
4
8
9
Charleston
West Virginia
Turnpike, I-77
Princeton

LEGEND

A. Cut Slopes
  1. Tuppers Creek
  2. Edens Fork
  3. Edens Fork
  4. Frame

B. Fill Slopes
  5. Charleston
  6. South Charleston
  7. New House Branch
  8. Frame and Amma

C. Medians
  9. Southwest of Clio

Figure 50 - Location of Experiments or Demonstrations in Kanawha County, West Virginia

B. Climate

The mean January temperature is 3.3°C (37.9°F) and the mean daily July temperature is 25°C (76.9°F). Although there is wide variation among years, the average growing season is 186 days with the average date for the last killing frost occurring the last week in April and the first killing frost about the 3rd week in October. The average rainfall is 115 cm (45.8 in.), and is normally greater during July and August than for any other 2-month period.

Intense summer thunderstorms of short duration which cause severe sheet erosion from disturbed areas, coupled with the high evapotranspiration, make it difficult to establish vegetation during the summer months. From November through March, low temperatures with freezing-thawing conditions inhibit germination and seedling growth.

C. Soils

Two soil associations, Gilpin-Upshur-Vandalia and Clymer-Dekalb-Gilpin, make up 86% of all soils within Kanawha County. The major soils within the two associations are Gilpin (acid), Upshur (acid), Clymer (acid), and Dekalb (acid) soils series. They were derived from geologic parent thick beds of materials consisting of red shale and acid sandstone, and thin interbedded strata of acid gray shale and siltstone. Moderately deep to shallow, these upland soils are well to excessively well drained. Generally they are medium to fine textured and with mixed illite, kaolinite, and vermiculite clay mineral fractions.

The surface horizons of soils are generally acid in reaction with a pH of around 5, low in organic matter and nitrogen, low in phosphorus, and medium to high in potassium. Because of the high cation exchange capacity associated with the clays, the calcium and magnesium levels are medium to high even with the acid soil conditions. Because of the high rainfall and leaching, there are no apparent toxic elements in the surface horizon.

The highway construction corridors involve massive cuts into bedrock and soil materials, creating long and steep cut and fill slopes. Thus, on construction sites, the major soil materials on which vegetation is to be established are in decreasing order, parent materials, subsoils, and very small amounts of the surface soil horizons. (See Figures 1 and 2, maps of soils and parent materials in Section I.)

Soil conditions for the different demonstration and experimental sites will be indentified by a soil series complex name; i.e., Gilpin-Upshur, or Clymer-Dekalb.

In the new U.S. system of soil taxonomy, the four soil series are classified as follows:

Gilpin-Typic Hapludults, fine-loamy, mixed, mesic
Upshur-Typic Hapludalfs, fine, mixed, mesic
Clymer-Typic Hapludults, fine-loamy, mixed, mesic
Dekalb-Typic Dystrochrepts, loamy-skeletal, mixed, mesic

(See Section I for the extent of the soil Great Groups of Hapludults, Hapludalfs, and Dystrochrepts.)

II. THE PROBLEM

The construction of interstate highways in the mountainous topography of the Appalachian Mountain Region makes it necessary to disturb tremendous areas and amounts of soil and rock materials. Cut and fill slopes are often long and steep. Destroying the natural protective woody vegetation and exposing bare soil materials, during and after construction, often results in severe sheet and gully erosion. Erosion in drainage ditches and on medians is the principal source of sediments.

It is recognized that establishing a stable vegetative cover is the best way to control erosion. The low fertility of these soil Great Groups, Hapludults, Hapludalfs, and Dystrochrepts, coupled with their fine texture, freezing-thawing conditions, and torrential rainstorms, have created severe restrictions on the establishment of protective vegetative covers. Torrential rains and uncontrolled water movement have caused severe sheet and gully erosion and subsequent water pollution.

Erosion on newly constructed cut and fill slopes after seeding is allied with the poor vegetative cover caused by inadequate fertilization. Soil materials are consistently low in organic matter and nitrogen; phosphorus varies in availability among soils, but soil acidity is not considered a serious problem. The poor persistence of the vegetative cover from new seeding is attributed to a lack of maintenance fertilizer. Low soil nitrogen is a critical factor for grass persistence, and leguminous plants might resolve this problem of low soil nitrogen and degenerating vegetative cover.

Because of the sparse vegetative cover on slopes covered with these infertile soil materials and the accompanying erosion problems, personnel of the West Virginia Department of Highways, in cooperation with the U.S. Bureau of Public Transportation, initiated a research contract to investigate methods of grading and establishing persistent vegetation on construction sites with research personnel of the Agronomy Department of Virginia Polytechnic Institute and State University.

III. DESCRIPTION OF DEMONSTRATIONS

A. Cut Slopes

Demonstrations were established on steep cut slopes at three locations on I-77 north of Charleston (Figure 50). The areas had been contract seeded, but 2 or 3 years later the slopes were completely bare and severely eroded. One demonstration was established in three locations within 5 km (3 miles) of each other. Slopes were generally cut at 1:1 (45 degrees, 100%). They usually had hard surface conditions which was conducive to severe rill erosion. Wood-fiber cellulose was used in a water slurry to make seeds and fertilizer adhere to the slope surface. Treatment variables involved fertilizer quantities, nitrogen sources, chemical binders, grass species, multistep seeding, and mixtures and rates of seed. It was extremely difficult to establish vegetation because of adverse physical soil properties, infertility of the soil and rock materials, and the cut grading method. The experiments were in an area where the subsoil and parent material of the Gilpin-Upshur soil complex are very low in organic matter and nitrogen and low in available phosphorus because of the alkaline condition (pH 7.5 to 8.3) of the shale soil parent materials. Soil potassium was medium to high and adequate for growth. The dark reddish color of the shale and subsoil materials, coupled with the sunny southwest exposures and low water infiltration capacity, made it very difficult to establish a persistent vegetative cover for erosion control. The sunny exposures of the dark reddish color caused high absorption of radiant energy, high temperatures, and droughty conditions.

With conventional grading procedures here (benches spaced intermittently on cut slopes), cuts are designed with 2.8- to 5.6-m (10- to 20-ft) width horizontal benches. Such benches are spaced at intervals of 5.6 to 14.7 m (20 to 50 ft) along the cut slopes; the steepness of the slopes behind the benches varies with the hardness of consolidated materials. For example, 1/4:1 slopes are permitted with hard sandstone or limestone rock materials but 1:1 slopes behind benches are specified for less consolidated materials. Slopes are designed to be steeper as the materials are less friable.

With the present method of grading, materials falling on the benches usually remain in place except during extreme torrential rainstorms. Erosion from the basal slope, below the lowest bench, is usually more serious; however, severe rilling on cuts makes it difficult to establish vegetation for erosion control in this area (Figure 51).

Stair-step grading of cuts was initiated at three adjacent locations near Frame in Kanawha County along I-79. A demonstration involving different mixtures and dates of seeding, fertilizer rates, and nitrogen sources was established on a stair-step cut, composed of alkaline red shale subsoil and parent material of the Gilpin series in the Gilpin-Upshur soil complex. Two similar cuts were stair-step graded and seeded by the contractor.

B. Fill Slopes

West Virginia and some other States generally construct smooth hard surfaces (2:1 in steepness) on fill slopes by blading with a dozer or blading and then tracking vertically with a dozer. Although it is easier to establish vegetation on such fill slopes than on cut slopes, compaction of fill slopes causes low filtration and excessive runoff. This along with the low fertility often causes seeding failures and sheet and rill erosion. To investigate this problem, demonstrations were established on freshly constructed fill slopes and on old severely eroded fill slopes with sparsely developed vegetation.

One plant establishment demonstration was established on a fill slope compacted by a sheepsfoot roller and seeded progressively as it was being constructed. Then a comparison was made with plant establishment when a fill slope was bladed-tracked.

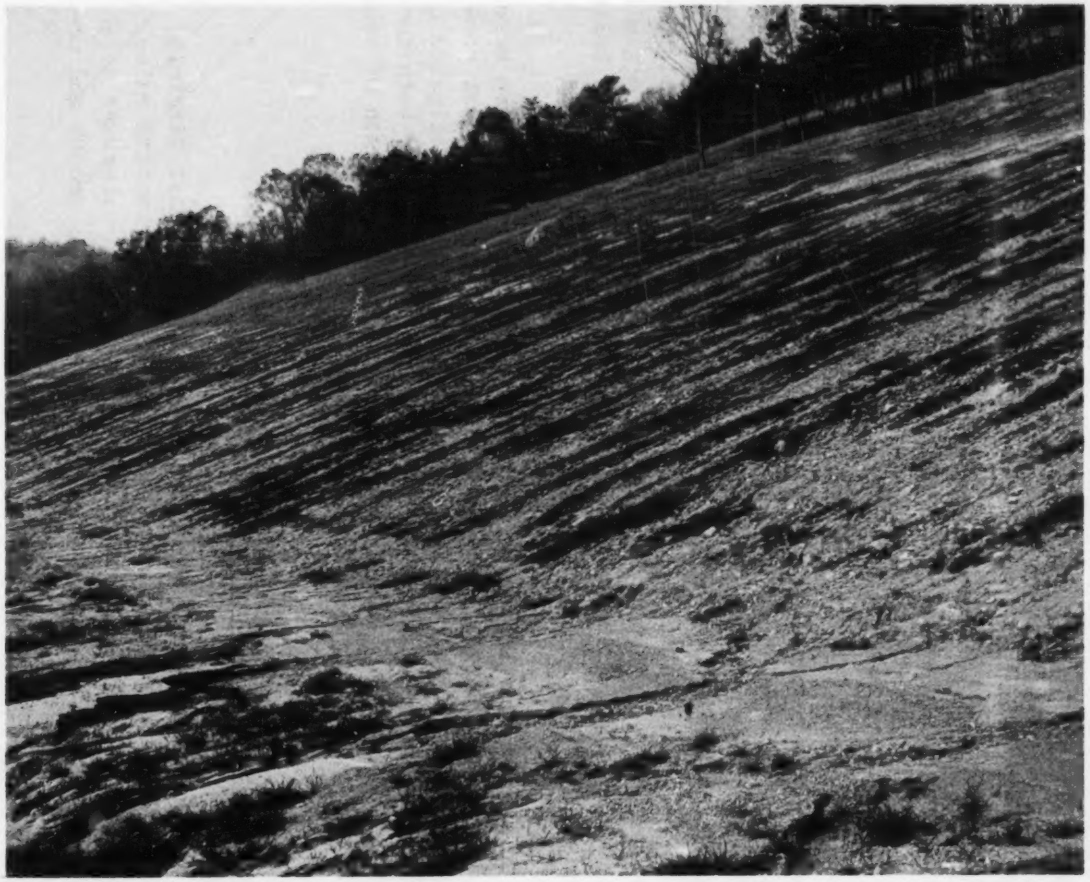


Figure 51 - A Steep Grade (2:1) in West Virginia was Given the Traditional Treatment of Smoothing, Fertilizing, and Seeding, but Failed for a Lack of Water-Control Structures and Insufficient Fertilizer and Mulch (Courtesy of Roy Blaser, Virginia Polytechnic Institute and State University)

Additional demonstrations were established on rough, loose slopes where rocks and soil materials were allowed to fall naturally as fill slopes were constructed. No mechanical equipment was allowed on these fill slopes to assure a loose, friable, undulating surface.

These demonstrations were at the following locations in the vicinity of Charleston in Kanawha County: four adjacent experiments in South Charleston with a southeast aspect, I-64 corridor; three adjacent experiments near Newhouse Branch, all with a generally southeast exposure, I-77 corridor; and seven experiments (three with east and four with west aspects) all in the general vicinity of Frame and Jordon's Creek, I-79 corridor (Figure 52).

All but two of the fills were constructed of the reddish alkaline (generally pH 7.5 to 8.3) subsoil and parent materials (Gilpin series of the Gilpin-Upshur complex). They were medium to high in potassium, low in available phosphorus, and very low in nitrogen. Two of the fills in South Charleston were constructed from mixed sandy and silty subsoil and parent materials (Dekalb series in the Clymer-Dekalb complex) that were brownish in color, acid in reaction (pH 5.0 to 5.2), medium in calcium and magnesium, low in phosphorus and potassium, and very low in organic matter and nitrogen. An abundance of porous sandstone made these soils very droughty.

The demonstrations were designed to obtain a vegetative cover quickly and then shift to a persistent leguminous vegetation that controls erosion and requires less maintenance. Variables investigated were: fertilizer rates; nitrogen sources; companion species; both temporary and permanent cool and warm season plant species; season of seeding; seeding rate; organic mulches; and chemical binders.

C. Medians and Grassed Waterways

In mountainous areas such as Kanawha County, West Virginia, there is often severe erosion in medians because of torrential rains and high water flows during highway construction. The waterways often gully severely due to the construction designs of long, smooth and uninterrupted slopes between drainage receptacles.

The mixture of soil, subsoil, and parent materials (Gilpin-Upshur soil complex) was slightly acid in reaction, low in available phosphorus, low to medium in potassium, very low in organic matter and nitrogen, and free of toxic elements. The median surfaces were very

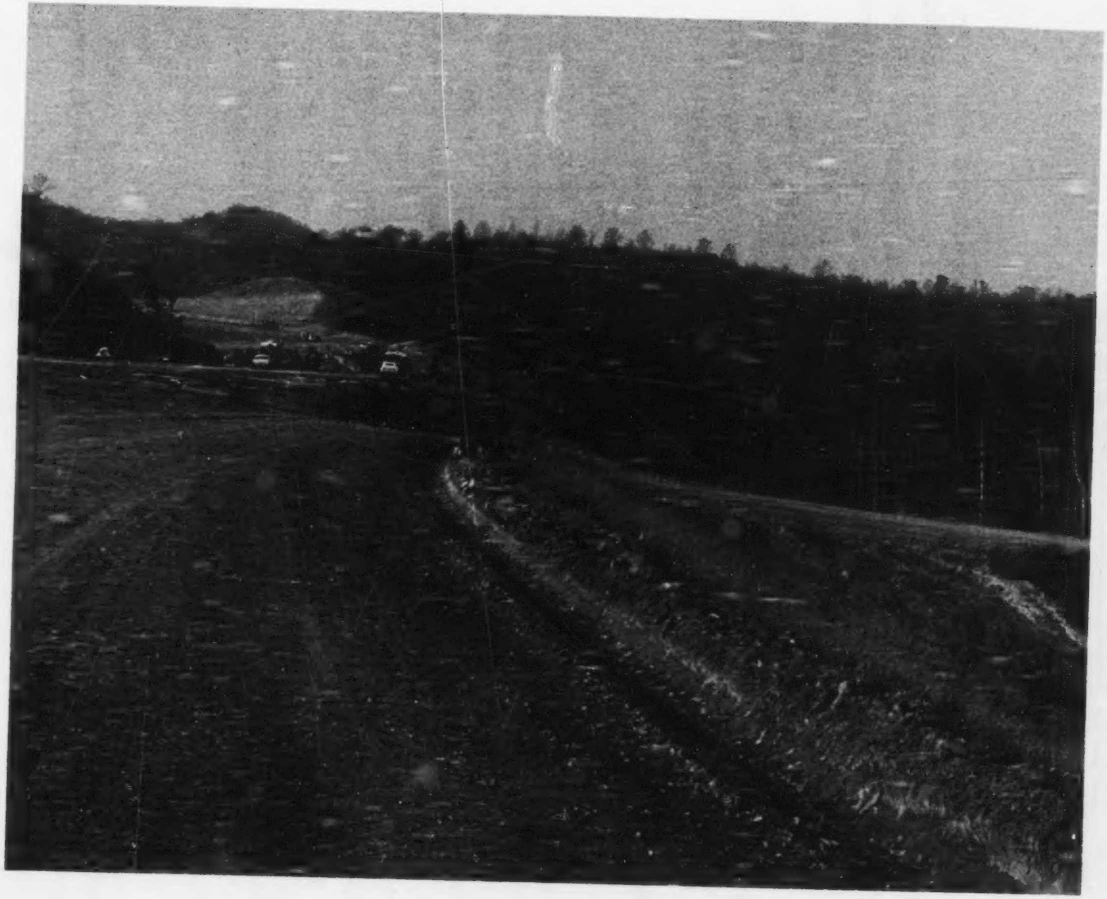


Figure 52 - On This Steep Fill Slope on the I-79 Corridor Near Frame and Jordon Creeks in West Virginia, the Ditch and Berm on the Right Side of the Road were Constructed to Divert the Excess Water Away from the Adjacent Slope so it Could be Quickly Vegetated (Courtesy of Roy Blaser, Virginia Polytechnic Institute and State University)

smooth, rock-free, and extremely compacted. Two demonstrations were established in medians with east-west aspects on I-79 near Clio (location No. 9, Figure 50). The treatment variables investigated were: sodding, jute matting, fiberglass, wood fiber, straw, and chemical binders.

IV. DEMONSTRATION EVALUATION AND RECOMMENDATIONS

A. Cut Slopes

1. Construction: The steep slopes with smooth and hard surfaces with the bench-grading method in mountainous regions, as described earlier, are difficult environments for establishing a vegetative cover. Even with several applications of seed and fertilizer, it has been found to be extremely difficult to establish vegetation because of the rapid sloughing of "soft" materials, low water infiltration, high evaporation, and low available soil water, especially on sunny slopes. Because of the severe sloughing and adverse environment for establishing vegetation with this conventional grading procedure, grading specification should be amended.

Cut slopes 2:1 or steeper in erodible materials should be of a stair-step design with the ratio of the vertical cut distance to the horizontal not to exceed 1:1. The vertical cuts should generally be not more than 100 cm (40 in.). The numerous small steps improve water infiltration, thus impending the flow of water off the cuts (Figure 53). Also, the sloughing of soft friable material from the many small vertical steps that falls and rests on the horizontal steps promotes seed and fertilizer coverage and creates a favorable environment for germination, seedling growth, and rapid establishment of a persistent vegetation. Stair-step grading also stimulates the encroachment of persistent leguminous vegetative cover as crownvetch. Accumulations of massive sloughings, with water and mud spilling over into drainageways, commonly occurs with conventional grading.

Cut slopes, 2:1 or shallower, should be graded to leave loose, undulating, rough surfaces to increase water infiltration and impede water flow. Such rough and loose surfaces make a favorable environment for quickly establishing a vegetative cover.

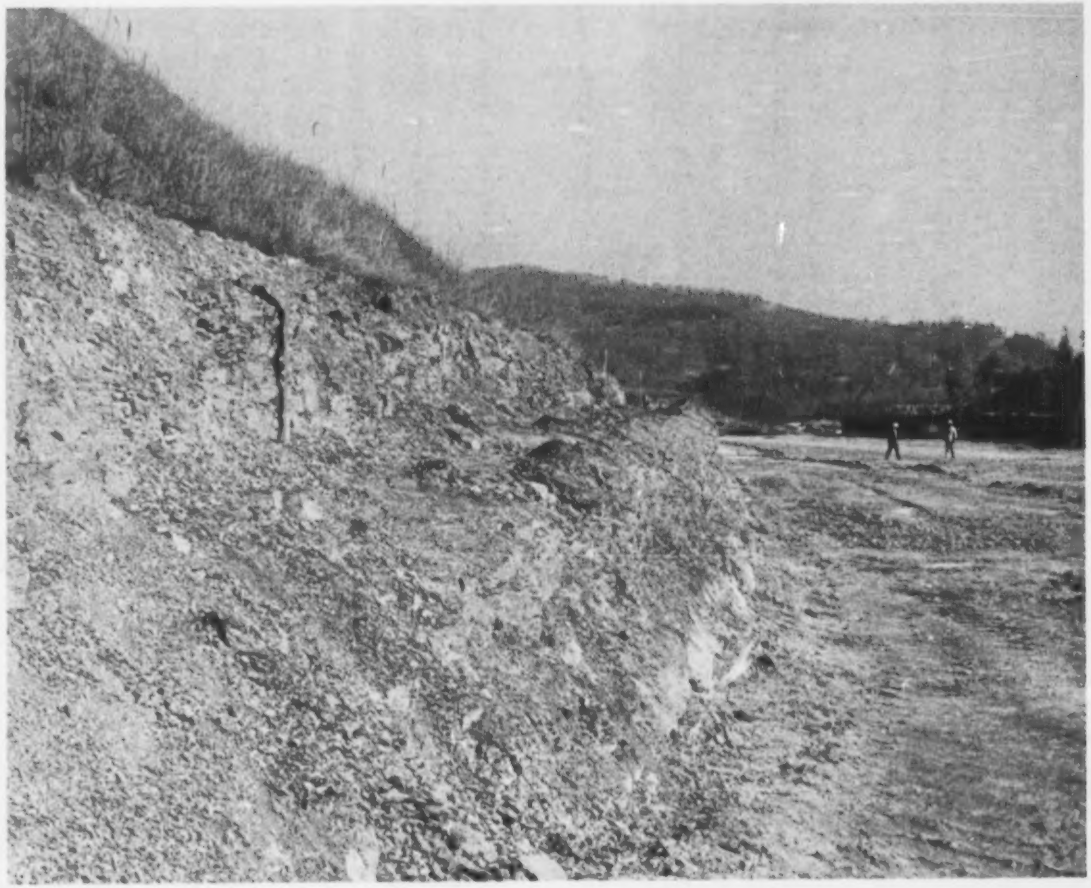


Figure 53 - On Cut Slopes of 2:1 and Steeper, the Bench and Stair-Step Design of Grading Permits the More Rapid Establishment of Vegetation for Control of Sediment (Courtesy of Roy Blaser, Virginia Polytechnic Institute and State University)

2. Fertilizing vegetation: Cut slopes should be seeded after each 4.5-m (15-ft) excavation or every 2 weeks, whichever occurs first, according to the West Virginia Department of Highways. The soil materials should first be analyzed for lime and fertilizer requirements. Tests are generally very reliable for lime and potassium diagnosis but overestimate soil phosphorus availability for plants, as chemical fixation of phosphates in these alkaline soil materials is high. Even though the surface soils are often very acid, lime has not been needed because the underlying parent materials are usually alkaline. Even when soil parent materials were quite acid, lime has not been needed to establish a persistent cover of crownvetch; this is attributed to the high base saturation and availability of cations in such soil materials and to the acid-tolerant crownvetch.

Excellent responses in plant growth for vegetative cover have been obtained from liberal applications of nitrogen and phosphorus such as with a 10-20-10 fertilizer. A 10-20-10 fertilizer at 1,121 kg/ha (1,000 lb/acre) is recommended, as high rates of nitrogen and phosphorus stimulate seedlings and subsequent growth to establish a vegetative cover quickly; also, the phosphorus is needed for a persistent leguminous cover such as crownvetch. To establish a grassy protective cover quickly, liberal nitrogen fertilization is necessary; later, leguminous plants may encroach and persist and supply their own nitrogen.

3. Mulches and binding agents: Mulching materials moderate soil temperatures, improve and prolong moisture availability, and stabilize soil and fertilizer materials. They improve and speed up germination, seedling growth, and the establishment of a protective vegetative cover to control erosion. Organic mulches such as straw, woodbark, woodchips, and wood fiber have given decided improvements in establishing persistent plant cover. No one mulch is best for all situations. For example, wood-fiber cellulose, applied in a water slurry, is the only mulch that adheres to soil to hold fertilizer and seed in place on 1:1 slopes and on steps. On the other hand, this mulch, compared to others, has a low rating during drought.

Straw at 3,360 to 4,480 kg/ha (3,000 to 4,000 lb/acre) along with a suitable binding agent such as asphalt or wood-fiber cellulose at 1,680 kg/ha (1.500 lb/acre) should be used during the March and September seeding season on cut slopes that are stair-step graded or flatter than 2:1. During the summer season or droughty periods (June to July) straw is generally superior to wood fiber for germination and obtaining a vegetative cover quickly.

During the November to February season, when low temperatures make it impossible to establish protective plant covers, a long-lasting plant cover can be provided with straw at 4,480 kg/ha (4,000 lb/acre) or more tacked with asphalt at about 1,875 liters/ha (200 gal/acre). Woodbark and woodchips applied at 112 to 168 m^3/ha (50 to 75 yd^3/acre) are excellent mulches that require no stabilization with binders on 2:1 cut slopes. Because of costs of application and availability of these mulches, they should be used primarily during the winter months when prolonged soil protection is necessary. Another alternative is direct sodding during the winter when temperatures permit.

Binding agents (pectin, latex, asphalt, and rubber-like emulsions) used by themselves have been unsatisfactory for controlling erosion or for helping to establish a vegetative cover. They are not usually needed during seasons which are favorable for seeding when protective vegetative covers develop readily. Suitable binders are needed, however, to prolong the persistence of mulches during unfavorable seasons and to aid in establishing vegetation.

4. Seeding: Designated plant species of warm and cool season origin are adapted to the environmental conditions on cut slopes in highway corridors in West Virginia when seeded during appropriate seasons on soil materials that have been adequately fertilized and mulched. Seed mixtures are planned for various seasons of seeding. All mixtures are designed to: (a) develop a protective grass cover rapidly with temporary species; (b) improve the density and persistence of the cover with perennial grasses; and (c) finally encourage plant succession to persistent perennial legumes. Grassy vegetation on cuts degnerates with time because of the acutely low organic matter and nitrogen in the soil material. Legumes like crownvetch and sericea lespedeza fix atmospheric nitrogen for growth and give very persistent vegetative cover; however, these legumes establish slowly because of poor seedling vigor. The legumes, white clover and birdsfoot trefoil, are quite persistent on the more favorable soil and moisture environments, especially for certain medians.

Species and rates of seeding for various seasons follow (Table 18):

TABLE 18

RECOMMENDED SPECIES AND SEEDING RATES BY SEASON FOR WEST VIRGINIA HIGHWAYS

Spring and Fall Seeding Seasons
(1 March to 30 May, and 15 August to 30 September)

Species	Seeding Rate	
	kg/ha	lb/acre
Kentucky-31 Fescuegrass	51	45
Creeping Red Fescuegrass	17	15
Annual Ryegrass	9	7
Crownvetch	17[a]	15

Summer Seeding Season
(30 May to 15 August)[b]

Species	Seeding Rate	
	kg/ha	lb/acre
Kentucky-31 Fescuegrass	51	45
Creeping Red Fescuegrass	17	15
Weeping Lovegrass	6 or	5 or
German Millet	17	15
Crownvetch	17	15

Autumn and Winter Seeding Season
(30 September to 1 March)[c]

Species	Seeding Rate	
	kg/ha	lb/acre
Cereal Rye	67	60
Creeping Red Fescuegrass	34	30
Kentucky-31 Fescuegrass	22	20

---

[a] Crownvetch should be inoculated with legume bacteria at 10 times the rate normally recommended by the manufacturers.

[b] Do not seed lovegrass later than 15 July.

[c] Increase seeding rates by 50% after 1 November; also overseed with crownvetch at 17 kg/ha (15 lb/acre) during March.

5. Additional seeding and fertilization: If stands of vegetative cover are not dense enough to give a protective cover, a second application of seed, fertilizer, and mulch should be applied during the first subsequent favorable season. After the initial seeding for bench grading with steep, hard, and smooth cut slope surfaces, it is imperative to apply one or more additional applications of fertilizer, seed, and mulch as the partial stands that generally occur need to be improved in density. Additional applications of fertilizer and seed when needed stimulate a persistent leguminous vegetation such as crownvetch.

Exhibits of additional (multi-step) applications are:

a. For initial seedins made during spring, apply a second application of fertilizer, seed, and mulch in late summer and a third treatment the following spring if the vegetative cover is unsatisfactory. For retreatments on existing stands of vegetation, apply approximately one-half of the initial rates of fertilizer, seed, and mulch.

b. For initial seedings made during the late summer to early fall, apply a second application in spring and a third in the subsequent late summer if needed.

c. For initial seedings made during winter, make a second application of seed and fertilizer the next spring if stands are poor, also using the initial rates; remulch if necessary.

B. Fill Slopes

1. Construction: The most favorable conditions for establishing a vegetative cover can be found on fill slopes, where the soil and rock materials fall naturally to form loose, rough, undulating slope surfaces. On the other hand, the common practices of blading or blading and tracking to get smooth "pleasing" surfaces are objectionable for several reasons:

(a) Such slopes become severely compacted by dozers which also form discrete hard clods that are severed from a continuous soil contact. These conditions reduce the soil capacity for infiltration; hence during heavy rains, surface waters flow rapidly down slopes to cause severe sheet and gully erosion. It is difficult to establish protective vegetative cover quickly on such slopes. Several applications of seed, fertilizer, and mulch are usually needed to get a suitable plant cover.

(b) Erosion rills inadvertently occur when these operations leave channels to concentrate water movement.

The desirability of loose, rough fill slope surfaces when rock and soil materials fall naturally as fills are made, as compared to tracked slopes, was verified on I-79 during construction in 1974. After a heavy 7.5-cm (3-in.) rain, there was severe sheet and gully erosion of around 800 mt/ha (400 tons/acre) on a tracked 2:1 fill slope. After the slope was reworked, retracked, seeded, and properly mulched, a 2.5-cm (1-in.) rain several days later caused severe erosion of all of the mulches and chemical binders. After fitting the slope a third time, a vegetative cover under favorable weather conditions was established. A similar 2:1 fill slope with loose rough surfaces and no mechanical equipment traversing the slopes absorbed the water from the heavy rains, and no appreciable water runoff and erosion resulted. A persistent vegetative cover was obtained on this slope irrespective of the mulching treatments.

During construction, it is strongly recommended that fill slopes be left rough and loose as described and that they be seeded to obtain vegetative cover every 2 weeks or at intervals of 3-m (10-ft) lifts, whichever occurs first.

2. Establishing vegetation: The recommendations given for lime, fertilizer, mulch, seed mixtures, and dates of seeding for cut slopes apply to fill slopes. It is easier to establish vegetation on fill than on cut slopes; however, the multi-step procedure of reapplying seed, fertilizer and mulch should be followed when initial stands are too sparse to control erosion. Sericea lespedeza may be substituted for crownvetch, especially on sunny slopes. If the former is used, it should be seeded only during the late winter to spring season (Figures 54 and 55).

C. Medians and Grassed Waterways

1. Construction: Slope surfaces of medians should be left with a rough surface condition. Lime and fertilizer materials should be incorporated by tillage to a depth of 7.5 to 15 cm (3 to 6 in.). Tillage reduces runoff, channelization of waters, and erosion; and water infiltration and moisture conditions are improved for quickly developing a vegetative cover.

Drainageways should be constructed to have flat bottom surfaces about 1 m (3.2 ft) wide rather than "V"-shaped ditches that concentrate and accelerate the water flow to cause severe erosion. When

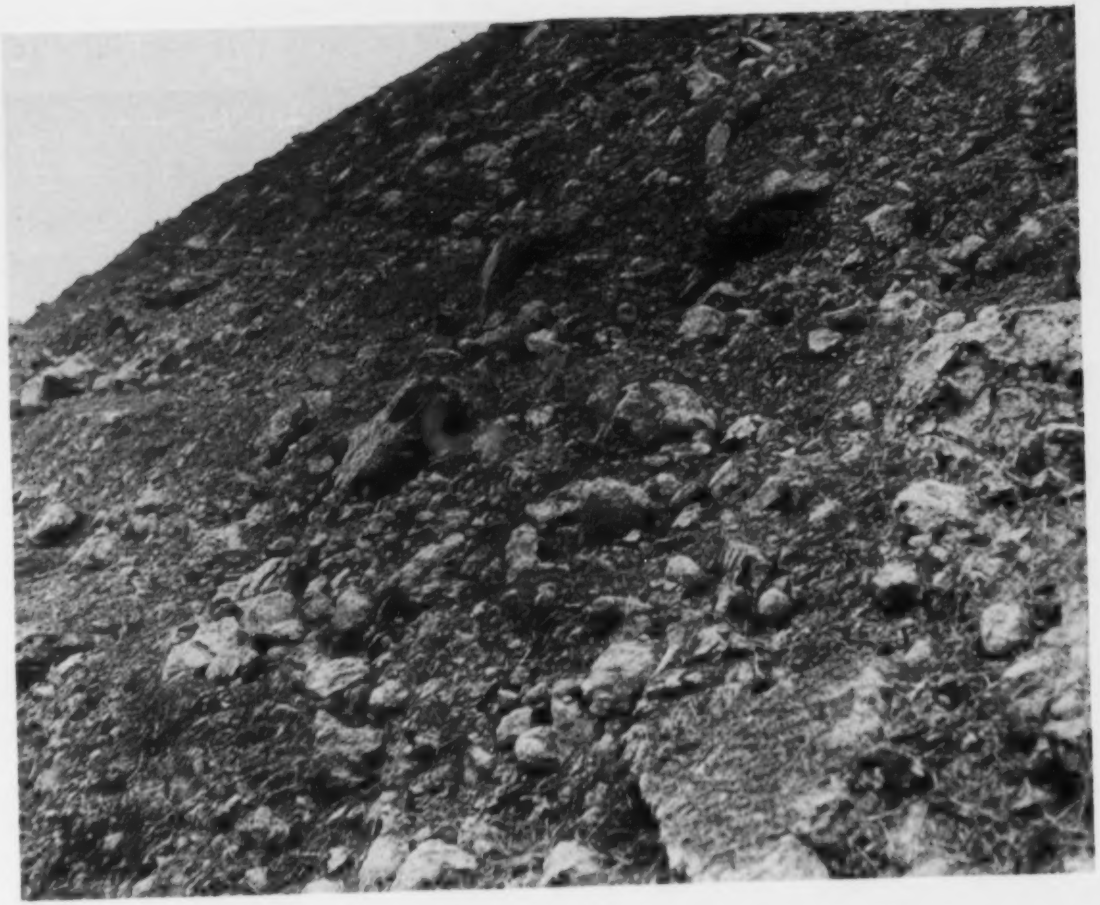


Figure 54 - A Fill Slope on Which the Soil has Just Been Overcast and Allowed to Seek Its Own Angle of Repose is a Better Plant Bed Than One That has Been "Manicured" With Heavy Equipment (see Figure 55). (Courtesy of Roy Blaser, Virginia Polytechnic Institute and State University)

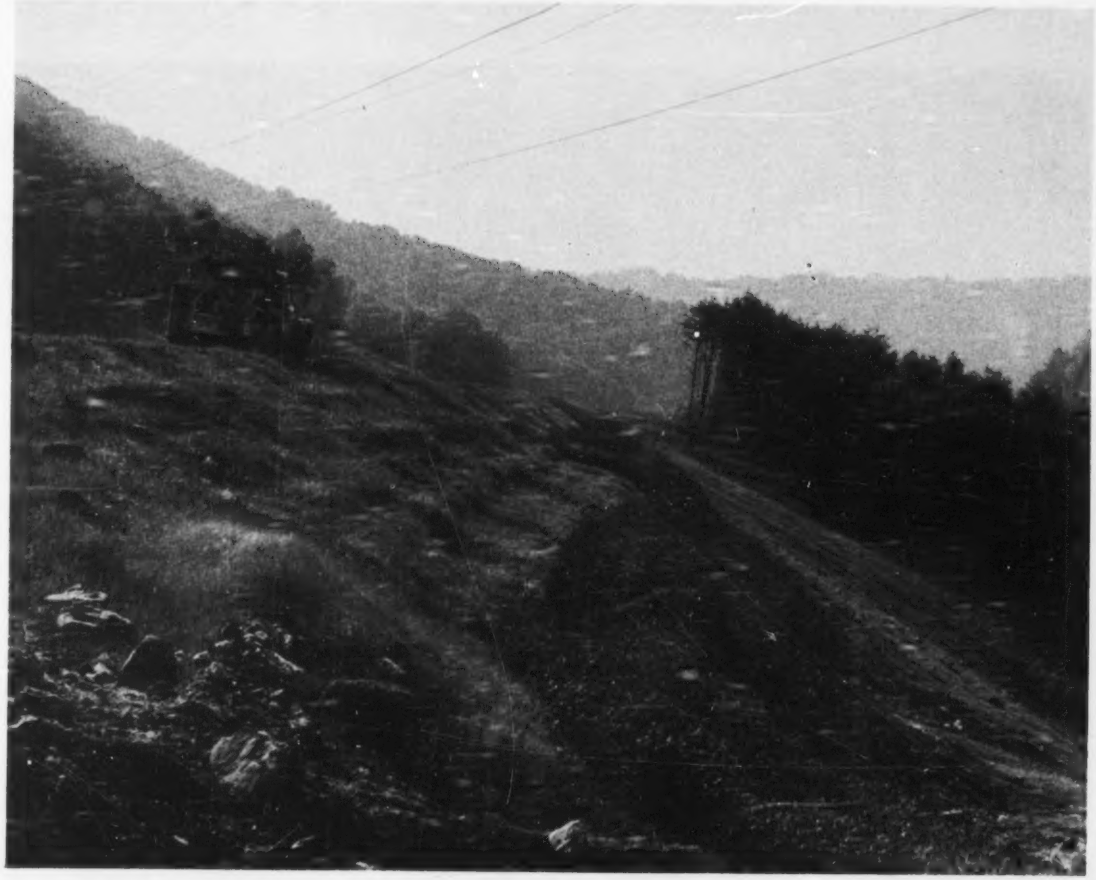


Figure 55 - The Same Fill Slope as in Figure 54 That has Been Benched and Seeded. The top strip is annual ryegrass, middle strip is weeping lovegrass, and the dark strip at the bottom is German millet (photo taken 2 months after seeding). (Courtesy of Roy Blaser, Virginia Polytechnic Institute and State University)

little water flow is anticipated, the drainageways may be seeded without special erosion control measures. Where considerable water flow is expected, sod from adapted plant species, or jute, fiberglass, or other suitable netlike materials may be used. Sodding is a superior treatment for waterways. Jute or other netting materials must be installed with complete soil contact to force water flow over the nets. Waterflow under the nets can cause erosion and vegetation failures. Fiberglass should be stabilized with asphalt applied at 1,875 to 3,750 liter/ha (200 to 400 gal/acre).

2. Establishing vegetation: The lime, fertilizer and mulching recommendations given for cut slopes should be used also for medians and grassed waterways. The seeding rates given for creeping red fescuegrass and Kentucky-31 fescuegrass for the spring to fall and the summer season should be reversed. For medians to be mowed, white or ladino clover at 4.5 kg/ha (4 lb/acre) should be substituted for crownvetch.

Recommendations for establishing trees and shrubs on critical areas in West Virginia include the species of multiflora rose, wichuraiana rose, autumn olive, black locust, Hall's honeysuckle, coralberry, shrub lespedeza, and Virginia pine. Spacing should be 1 x 1 m (3 x 3 ft) for shrubs and 2 x 2 m (6 x 6 ft) for trees. Overseed the planted area with a grass or a grass-legume mixture at half of the usual seeding rate, to stabilize the soil until the trees or shrubs become large enough to be protective. On some steep slopes or on highly erosive soils, a complete surface mulch is also necessary.

Procedures to establish protective vegetation on the roadsides of West Virginia are cogently summarized in this way:

a. Test the soil to determine lime requirements and fertilizer needs.

b. Select a mixture of grasses and legumes adapted to the soil and climate.

c. Determine the best mulch to use considering slope and season of the year. (Hydromulch for steep cut slopes, straw for erosive embankments.)

d. Apply lime, seed, fertilizer and hydromulch with a hydroseeder. The application of straw mulch requires a straw blower.

V. SOURCES OF FURTHER RESOURCE INFORMATION

Department of Agronomy
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061
703-951-6305

Office of Research and Special Studies Division
West Virginia Department of Highways
1900 Washington Street East
Charleston, West Virginia 25301
304-348-3339

Roadside Development Division
West Virginia Department of Highways
1900 Washington Street East
Charleston, West Virginia 25301
304-348-3338

Soil Conservation Service
1422 Federal Building
500 Quarrier Street
Charleston, West Virginia 25304
304-343-6181, Ext. 232

VI. ADDITIONAL REFERENCES

Blaser, R. E., and J. Woodruff, "The Need for Specifying Two- and Three-Step Seeding and Fertilization Practices for Establishing Sod on Highways," Highway Research Board, Washington, D.C., Highway Research Record, 246:44-49 (1968).

Green, J. T., Jr., R. E. Blaser, and H. D. Perry, "Establishing Persistent Vegetation on Cuts and Fills Along West Virginia Highways, 92 pages (1973).

Haught, O. L., "Geology of the Charleston Area," West Virginia Geological Survey Bulletin 34 (1968).

Henderlong, P. R., "Establishing and Maintaining Plant Cover Along Highways," West Virginia Department of Highways, SRC-26 (1968).

Perry, H. D., J. T. Green, and R. E. Blaser, "Establishing Vegetation on Steep Slopes Concurrently with and Subsequent to Highway Construction," Interim Report (1974).

Soil Conservation Service, Critical Area Planting Standards, Section IV-A, West Virginia, 2 pages (undated).

Staff, Guide for design in cut section through rock, Design Drawing No. 7, West Virginia Department of Highways (1964).

Staff, Stand specifications--rocks and bridges, West Virginia Department of Highways (1972).

Staff, West Virginia Department of Highways: Supplemental Specifications (1974).

West Virginia Department of Highways, Personal Communication to R. E. Blaser, dated 7 October 1974.

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VIRGINIA--DEMONSTRATION AREA NUMBER 8

VEGETATING HIGHWAY CORRIDORS IN THE PIEDMONT PLATEAU

Summary

Soils in the Piedmont Plateau are in general well drained, highly leached, low in plant nutrients, and acid. Favoring the rapid establishment of vegetation are the moderate temperatures and adequate precipitation. The soils on the demonstration site are highly erosive and are classified as the soil Great Group of Hapludults. Lime is usually necessary on soils testing below pH 5.5; without lime the redtop grass dominates the seeded vegetation, and it soon dies. In general, lime, nitrogen, and phosphorus are required to quickly establish a stand of vegetation. A mulch, net, or successful chemical binding agents is also necessary after a seeding to hold the soil in place until the plants become firmly established. A straw mulch has proved superior to all others tested. Kentucky-31 fescuegrass has been the best perennial cool-season grass for stabilizing slopes when adequate lime, fertilizers, and mulch have been used. On soils of low fertility and on south slopes, redtop grass and weeping lovegrass are most effective. Effective annual crops include rye, wheat, annual ryegrass, and German millet. Crownvetch and sericea lespedeza are perennial legumes that are used on slopes, not mowed, but seedling vigor is low. Documentation is also given for rapid establishment of vegetation on a grassed waterway, pond embankment, and spillway.

I. HIGHWAYS

A. Introduction

1. Location: Within the Piedmont Plateau the specific demonstrations are located along highways U.S. 58 and U.S. 360 in Halifax County located in central southern Virginia about 170 km (110 miles) southwest of Richmond adjoining the State of North Carolina (Figure 56). The county, roughly triangular in shape, has an area of about 208,384 ha (520,960 acres); elevations range from about 90 to nearly 180 m (300 to 600 ft); the main drainage areas are Dan, Roanoke, Banister, and Hyco Rivers, which receive waters from numerous creeks and intermittent streams.

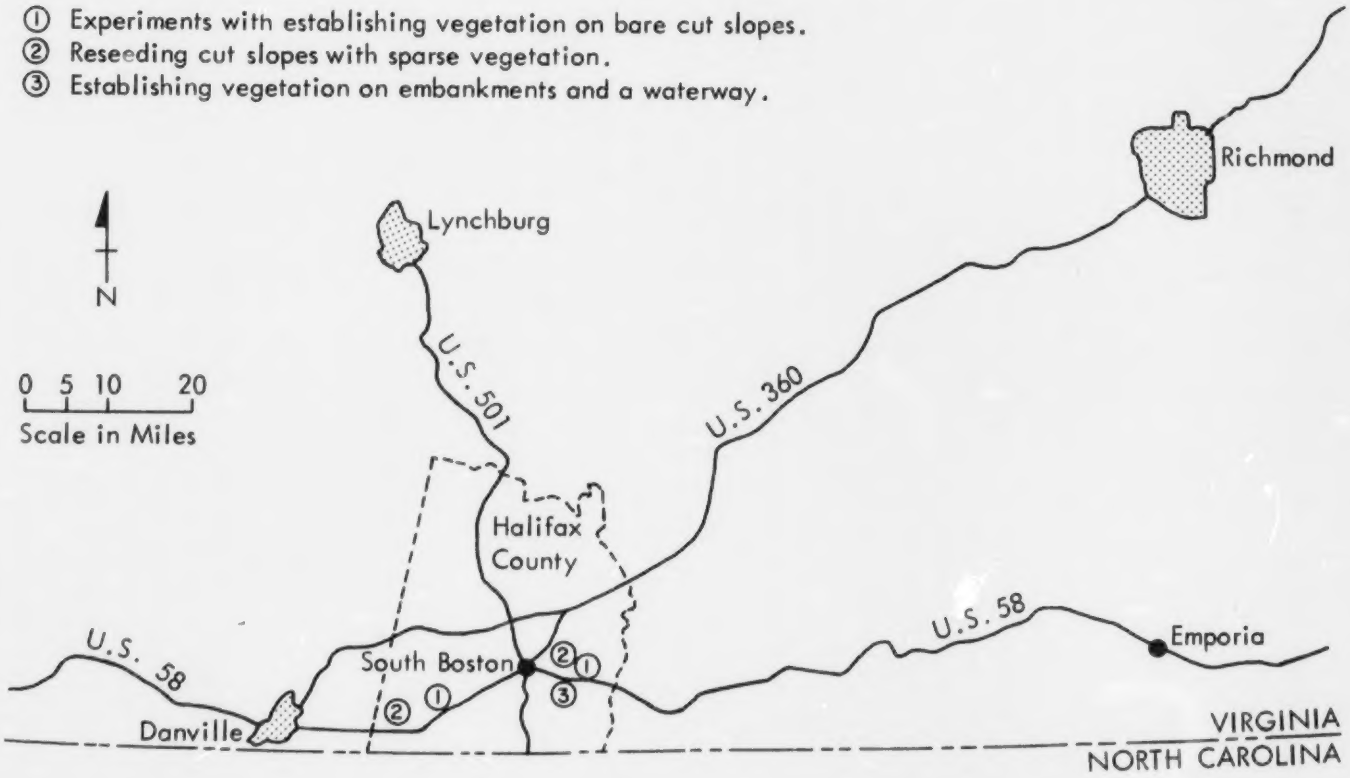
① Experiments with establishing vegetation on bare cut slopes.
② Reseeding cut slopes with sparse vegetation.
③ Establishing vegetation on embankments and a waterway.
N
0 5 10 20
Scale in Miles
Richmond
Lynchburg
U.S. 501
U.S. 360
Halifax
County
U.S. 58
U.S. 58
South Boston
Danville
Emporia
②
①
②
①
③
VIRGINIA
NORTH CAROLINA

Figure 56 - Location of Demonstrations on Establishing Roadside Vegetation in Halifax County, Virginia

U.S. Highway 58 crosses the southern part of the county in an east-to-west direction, and U.S. 360 crosses the central part of the county from northeast to southwest.

2. Climate: The mean January temperature ranges from 3.3 to 8.3°C (38 to 47°F) and the mean daily July temperature ranges from 22.8 to 27.2°C (72 to 81°F). The frost-free days range from 180 to 240 days. The last killing frost in spring generally occurs during the 1st week in April and the 1st killing frost in autumn occurs on about 30 October, but there is much variation among years. The average annual rainfall is about 107 cm (42 in.) with rather uniform monthly distribution.

Difficult periods for establishing vegetation are during the midsummer months of drought when monthly evapotranspiration is often double the amount of rainfall. Low temperatures and freezing soils during the late autumn and winter months inhibit germination and growth of seedling plants.

3. Soils: The soils are acid in reaction, low in fertility, and highly erosive when disturbed. Calcium and phosphorus are very low. Under the naturally acid conditions of surface soils and subsoils, high soluble aluminum, low calcium, and low phosphorus inhibit the growth of most of the grasses and legumes used for obtaining vegetative covers. In addition, on disturbed soils, low soil organic matter allied with poor soil structure inhibit water infiltration, thereby augmenting the erosive processes. Soil organic matter is low, resulting in the release of very small amounts of nitrogen for plant growth.

Granites, gneisses, and mica schist are the principal bedrock materials underlying soils in most parts of Halifax County.

The processes of physical, chemical, and biological weathering have reduced the bedrock to soft pliable material which varies from place to place. This material has given rise to soils of the Cecil, Appling, and Durham series.

According to the new U.S. system of soil taxonomy, these three soil series are classified as follows:

Cecil - Typic Hapludults, clayey, kaolinitic, thermic
Appling - Typic Hapludults, clayey, kaolinitic, thermic
Durham - Typic Hapludults, fine-loamy, siliceous, thermic

B. The Problem

During highway construction in the Piedmont Plateau, grading specifications generally call for 1:1 slopes on cuts, resulting in hard and smooth surfaces. Seeding for vegetative cover was generally delayed until highway construction was nearly complete, and such delays caused vertical rilling from uncontrolled water movement. This made it very difficult to establish a protective vegetative cover.

The seeding specifications for the highway construction corridor made by contractors or by personnel of the Virginia Highway Department consisted of 561 to 674 kg/ha (500 to 600 lb/acre) of a 10-6-4 fertilizer and a seeding mixture of redtop, creeping red fescuegrass, chewings fescuegrass, orchardgrass, and red clover. A straw mulch is used for both cut and fill slopes. Specifications for medians were similar, except that a redtop--creeping red fescue--chewings fescue--white clover mixture was used. Fertilizer and seed were applied in a slurry with a hydromulcher.

Cut clopes were staked on 60-cm (2-ft) centers, and the stakes protruded about 25 cm (10 in.) to hold the straw mulch in place. A light spray of asphalt as a binder was often applied with the straw mulch.

These grading and seeding practices obtained fair results in establishing protective vegetative covers on fill slopes and medians. Reseeding and refertilizing, however, were often necessary to develop a persistent vegetative cover. On the other hand, the usual fertilizer, seed, and mulch treatments usually failed to give a satisfactory vegetative cover to control erosion on cut slopes. Several reapplications of seed and fertilizer improved the vegetative cover but even with retreatments, steep cut slopes with sunny exposures often had sparse vegetation and severe erosion. In a final effort to obtain a suitable plant cover on the cut slopes, various woody species adapted to these infertile soils were hand planted. The plant cover developed too slowly for erosion control purposes and so was not satisfactory.

The poor vegetative cover did little to control erosion. This resulted in coarse-grained particles being deposited in the highway construction corridor and fine materials being transported further downstream, causing pollution. To resolve these problems, the Virginia Highway ReSearch Council entered into a research agreement with the Virginia Polytechnic Institute and State University.

C. Demonstrations

Several sites on the westbound lanes of U.S. 58 in the vicinity of Turbeville were used for establishing demonstrations to solve the problems of successful establishment of persistent vegetative covers. All cut slopes were established on a grade of 1:1 and "smooth" graded; seeding practices were generally delayed until construction was nearly finished. This delay resulted in slope erosion caused by an erodible soil and smoothly graded steep slopes. These factors added to the difficulty of establishing vegetation. The cut slope faces ranged from 5 to 15 m (16 to 50 ft) in height. Slopes, generally more than 90 m (30 ft) in length, were selected to apply treatment variables on plots 4 to 6 m (12 to 20 ft) wide paralleling the slope face. The treatment variables were replicated and subjected to statistical analyses.

A soil sample to a depth of 15 cm (6 in.) was taken on a reddish, friable clay loam subsoil (Cecil series) and sent for chemical fertility testing. The test results were as follows: CaO, K_2O, and P_2O_5 were all very low; however, MgO was high. Organic matter content was near nil; hence, nitrogen was near zero. The soil was very acid, with pH 4.6.

Demonstrations were established on bare soil on 1:1 cut slopes. The objectives were: (a) to obtain a vegetative cover quickly, and (b) to obtain a persistent cover requiring little maintenance. The following variables were investigated:

1. Rates of applying lime.

2. Rates of apply N-P-K fertilizers.

3. Slowly available and soluble sources of N.

4. Single versus several applications of N-P-K.

5. The adaptation of perennial grasses and legumes for designing seed mixtures.

6. The use of companion species.

7. The place of temporary species.

8. The differential responses of plant species to lime and fertilizer.

9. Mulching treatments including nets.

10. Using wood stakes to hold straw in place.

11. Establishing lateral grooves across slopes 8 to 10 cm (3 to 4 in.) deep and 35 to 50 cm (14 to 20 in.) apart.

12. Other experiments with similar Piedmont soils but at different locations also investigated these factors and included topsoiling, grading methods, and erosion control during all seasons by altering seeding mixtures, and prolonged soil cover with special mulching practices.

D. Evaluation and Recommendations

1. Grading: Cut slopes should be as flat as practical, preferably 2:1 or less. Steeper slopes should be stair-step graded or left serrate with about 30-cm (1-ft) serrations. Shallower cut slopes should have "rough," loose surfaces leaving stones and rocks in place to give varying slope exposure and microenvironments. Such slope conditions improve water infiltration, give some seed, lime, and fertilizer coverage to speed up germination and seedling growth. Such conditions have been especially favorable for establishing crownvetch, a persistent legume requiring no maintenance for many years. Establishing a vegetative cover quickly is the best way to arrest erosion.

Seedings should be made about weekly or as gradings of 3- to 5-m (10- to 15-ft) vertical sections are ready. It is better to establish vegetation right after grading as delays cause soil crusting or erosion, resulting in a very adverse environment for establishing vegetation.

Pursuing these procedures avoids the need for topsoiling. Topsoils in this region are generally of poor quality and difficult to identify. They are also sources of weed seeds. Topsoiling often causes delays in seeding and may allow seeds of weed species to grow and shade out more desirable persistent species.

2. Liming: Liming the reddish Piedmont subsoil materials (Cecil series) increases the soil pH and precipitates soluble aluminum, adds calcium, and improves phosphate availability (Table 19). Grasses and legumes that need lime on these soils are Kentucky-31 fescuegrass, Kentucky bluegrass, creeping red fescuegrass, orchardgrass, perennial

TABLE 19

CHEMICAL ANALYSIS OF A PIEDMONT SUBSOIL FROM A CUT SLOPE ALONG U.S. HIGHWAY 58, 5 YEARS AFTER LIMING AND FERTILIZING TO ESTABLISH VEGETATIVE COVER FOR EROSION CONTROL[a]

Quantity of Material Applied[b]				Acidity	Analysis of Soil			
Phosphorus		Lime			Phosphorus			Soluble Aluminum
					Available		Total	
kg/ha	lb/acre	kg/ha	tons/acre	(pH)	kg/ha	lb/acre	ppm	me/100 g of Soil
25	22	0	0	4.5	11	10	329	2.10
49	44	0	0	4.5	18	16	312	1.80
448	400	0	0	4.5	161	144	744	3.18
25	22	2	2	7.4	7	6	171	0.0
49	44	2	2	7.6	19	17	229	0.0
112	100	2	2	6.9	143	128	888	0.0
224	200	2	2	6.8	222	198	1,319	0.0

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[a] McKee et al. (1965).

[b] Nitrogen and potassium were uniformly applied over all treatments.

ryegrass, bermuda grass, cereal grains (used as companion crops), crownvetch, birdsfoot trefoil, and clovers. Sericea lespedeza and redtop grass are tolerant of the low calcium--high soluble aluminum in such red subsoils, but often also respond to lime. A Kentucky-31 fescue--redtop grass mixture becomes dominated by fescuegrass in a limed soil to form a persistent cover; without lime, redtop dominates the vegetative cover, while fescuegrass soon dies. Redtop is an undesirable shallow-rooted, shortlived species.

Liming of acid soil materials in the Piedmont Plateau adds calcium and sometimes magnesium as a neutralizing agent, reduces acidity, and decreases toxic soluble aluminum, making it possible to grown crownvetch. A finely ground dolomitic, agricultural limestone (around 30% magnesium carbonate and 70% calcium carbonate) applied at the rate of 4.5 mt/ha (2 tons/acre) has generally been adequate. Surface applications of lime have been successful; however, stands develop into a dense persistent cover much faster when lime is incorporated by tillage operations or if surfaces are loose or stair-step graded to obtain natural incorporation of lime.

3. Fertilization: Because of the very low availability of phosphorus and soil nitrogen in these red to yellowish subsoils (Cecil and Appling series), seedling growth responses and vegetative cover were hastened by liberal applications of N and P_2O_5. In the presence of lime, excellent vegetative covers with strong root systems to inhibit erosion were obtained within 6 to 8 weeks. However, about 6 months after seeding, when applying a 10-20-10 fertilizer at 1,120 kg/ha (1,000 lb/acre), the vegetation (predominately Kentucky-31 fescuegrass) became yellowish and stunted, causing canopy cover to become sparse. This depressed growth occurred because of the low soil organic matter and nitrogen. A second application of a 10-20-10 fertilizer at 560 kg/ha (500 lb/acre) about 6 months after seeding stimulated growth and improved the density of the vegetation. On a soil low in phosphorus, roadside vegetation establishment is a failure without phosphorus fertilizer (Figure 57). The most persistent cover occured, however, when a third application of fertilizer was applied a year after the second application. As an alternative, an excellent persistent vegetative cover was generally obtained when applying around 179 kg/ha (160 lb/acre) of N from a slow-release ureaformaldehyde nitrogen source along the initial application of 10-20-10 fertilizer. Responses in color and growth of grass were apparent several years after application.

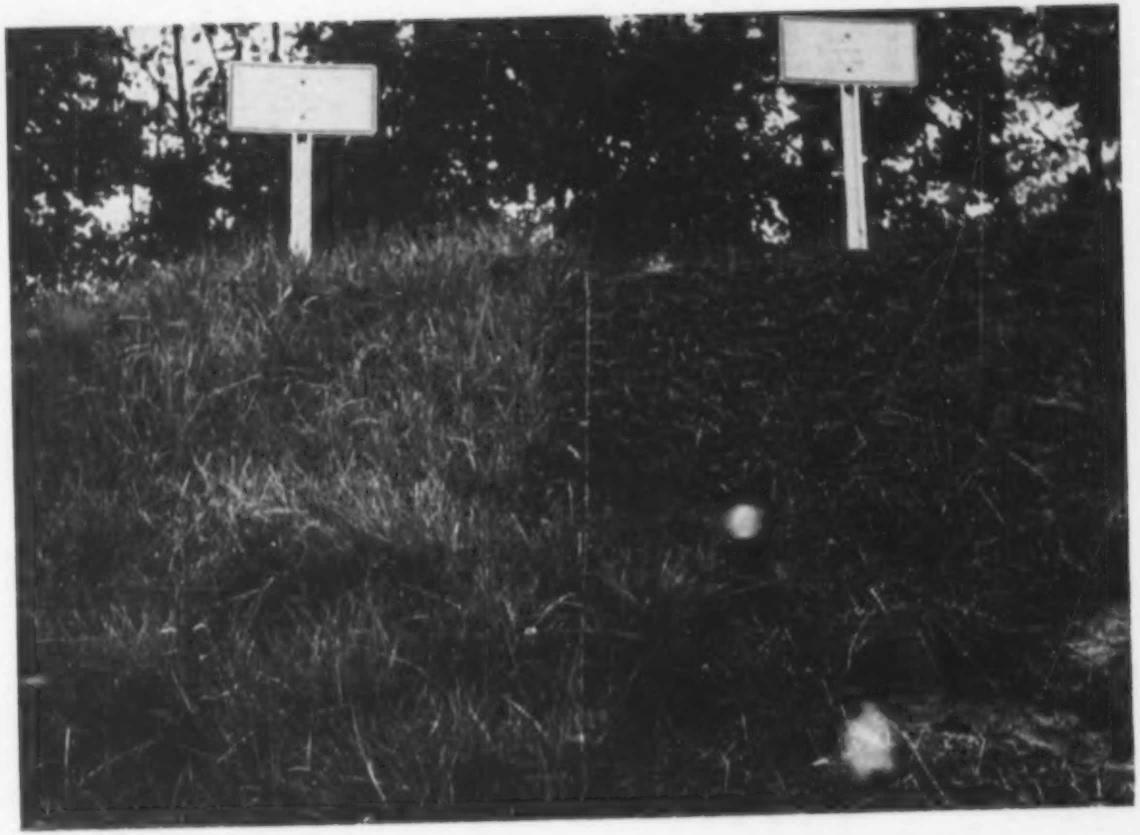

Figure 57 - Both Plots Received the Same Treatments Except That on the Right no Phosphorus Fertilizer was Applied. Vegetation establishment was a failure. (Courtesy Roy Blaser, Virginia Polytechnic Institute and State University)

4. Mulches, nets, and binding agents: Good mulches (a) increase infiltration of water into soils; (b) moderate temperatures; (c) decrease evaporation and prolong periods of favorable moisture; and (d) stabilize surface soils and fertilizer in place while seeds are germinating and developing a protective cover.

Of all mulch materials tested on steep 1:1 slopes with hard, smooth surfaces, straw and wood-fiber cellulose gave the best vegetative cover. Binding agents such as asphalt, latex, and other chemicals used alone were unsatisfactory. They gave results similar to no-mulch treatments. Nets varying in mesh size and weight were very unsatisfactory, as erosion started in areas where there was no soil contact. The major problem was water movement under the nets rather than over the surface.

The least erosion and best vegetative cover occured when the slopes were grooved on the contour before applying lime, fertilizer, seed, and mulch. Straw mulch applied at 3 to 4 mt/ha (1.5 to 2.0 tons/acre) and held in place with an asphalt spray, net, or with string, gave the best vegetative cover in a shorter period of time than any other mulch. Wood fiber at 2 mt/ha (0.85 tons/acre) was the next best mulch. During the favorable seeding seasons either wood fiber or straw mulch were satisfactory; but during moisture stress periods or for prolonged protection of the soils, straw, woodbark, or woodchips at about 170 m/ha^2 (550 $yd/acre^2$) were the best mulches.

Chemical agents to bind wood fiber, straw, or woodbark were of negligible value on slopes that were the most difficult to vegetate. Of all binding agents tested, asphalt on straw has given the best response.

5. Seed mixtures: Seed mixtures should be designed to obtain a protective soil cover, e.g., a rapidly developing canopy to inhibit raindrops from dispersing soil fines that plug the channels through which water moves into soils. Simultaneously, strong root systems from adapted plants bind soil materials together to minimize erosion. Seeding mixtures should be designed for the soil environments including moisture, pH, and mineral nutrient status; latitude; altitude; biological factors such as diseases and insects; season of seeding; and local slope environments.

More fertilizer, seed, and more adequate mulching are required on hot sunny slopes than on cool shady ones. Sunny slope exposures encounter sharply higher temperatures than shady ones because of high intensities of radiant energy. The high temperature in turn causes high evaporation and transpiration. Droughty conditions then inhibit germination, seedling growth, and vegetative development. Thus, hot sunny slopes require more fertilizer, seed, and better mulching than do cool shady slopes.

Seed mixtures should have small amounts of temporary species (annual ryegrass, cereal grains, or German millet) that provide a vegetative cover quickly; the species will vary with season of seedling. Excessive amounts of temporary species give a quick vegetative cover, but later the soil often becomes bare and eroded because desirable perennials that start slowly were shaded and killed.

Tall fescuegrass (cultivar Kentucky-31) is a hardy perennial that is better adapted to the wide array of environmental factors than any other cool season grass (Table 20). Redtop has been included in mixtures because it gives a vegetative cover quickly, especially under acid soil conditions high in soluble aluminum; however, this species is short-lived. Weeping lovegrass, a warm season perennial, seeded during the warm frost-free spring to early summer season is the best grass for adverse (dry and hot) cut slope environments. It responds to lime and needs to be fertilized liberally with P_2O_5 and N. Excellent stands are being obtained in the corridor of major and secondary highways in the Piedmont Plateau. Cut slopes in major and secondary highway corridors in the Piedmont regions seeded with a hydroseeder in a wood-fiber mulch--fertilizer--lovegrass seed slurry have developed excellent vegetative cover quickly. Common bermuda grass seeded with tall fescue mixtures contributes to the vegetative cover on "hot slopes" where it is often the dominant species in canopy cover. On shady slopes, however, the cooler temperatures and more favorable moisture cause tall fescuegrass to suppress bermuda grass.

Cool season grasses, such as bluegrass, creeping red fescuegrass and bromegrass, and legumes such as red and white clover are not adapted to the harsh soil environment and droughty period with high temperatures. The low organic matter and low soil nitrogen result in slow growth and degeneration of grass sods unless nitrogen fertilizer is applied or perennial legumes are seeded to fix nitrogen. Annual lespedeza is well adapted to the infertile soil conditions in the Piedmont; but its short (5 months) season of growth and fine shallow decaying roots allow severe erosion during the winter. The perennial legume, sericea lespedeza, is exceptionally well adapted to the highly infertile red and yellowish soils and subsoils in the Piedmont Plateau. The primary problem with this legume is its slowness in developing stands because of slow seedling growth the 1st year. For bare cut slopes, it is necessary to lime and fertilize to establish a cover with such perennial grasses as tall fescuegrass; later sericea lespedeza plants from early and delayed germination will develop a very persistent protective cover which requires a little maintenance for many years (Figure 58).

TABLE 20

RECOMMENDED SPECIES AND SEEDING RATE BY SEASON FOR VIRGINIA HIGHWAYS

Spring and Fall Seeding Seasons
(15 February to 15 May, and 1 September to 15 October)

Species	Seeding Rate	
	kg/ha	lb/acre
Kentucky-31 Fescuegrass	55	50
Creeping Red Fescuegrass	11	10
Annual Ryegrass	11	10
Sericea Lespedeza	34[a]	30

Summer Seeding Season
(15 May to 1 September)[b]

Species	Seeding Rate	
	kg/ha	lb/acre
Kentucky-31 Fescuegrass	55	50
Creeping Red Fescuegrass	11	10
Weeping Lovegrass	6 or	5 or
German Millet	17	15
Sericea Lespedeza	34	30

Autumn and Winter Seeding Seasons
(15 October to 15 February)[c]

Species	Seeding Rate	
	kg/ha	lb/acre
Cereal Rye	67	60
Creeping Red Fescuegrass	22	20
Kentucky-31 Fescuegrass	44	40

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[a] Crownvetch and lespedeza should be inoculated at 10 times the rate normally recommended by the manufacturers. Crownvetch at 22 kg/ha (20 lb/acre) may be substituted, especially on cool slopes and with liberal and incorporated lime and phosphorus. A soil pH of 5.8 or higher is desirable for crownvetch. Redtop at 2.2 kg/ha (2 lb/acre) may be added; this grass thrives under acid-high aluminum soil conditions.

[b] Do not use lovegrass later than 1 August; it would be best to seed the sericea lespedeza or crownvetch the subsequent spring.

[c] Increase seeding rates to 50% after 15 November; also overseed with crownvetch at 22 kg/ha (20 lb/acre) or sericea lespedeza at 33 kg/ha (30 lb/acre) the next spring.

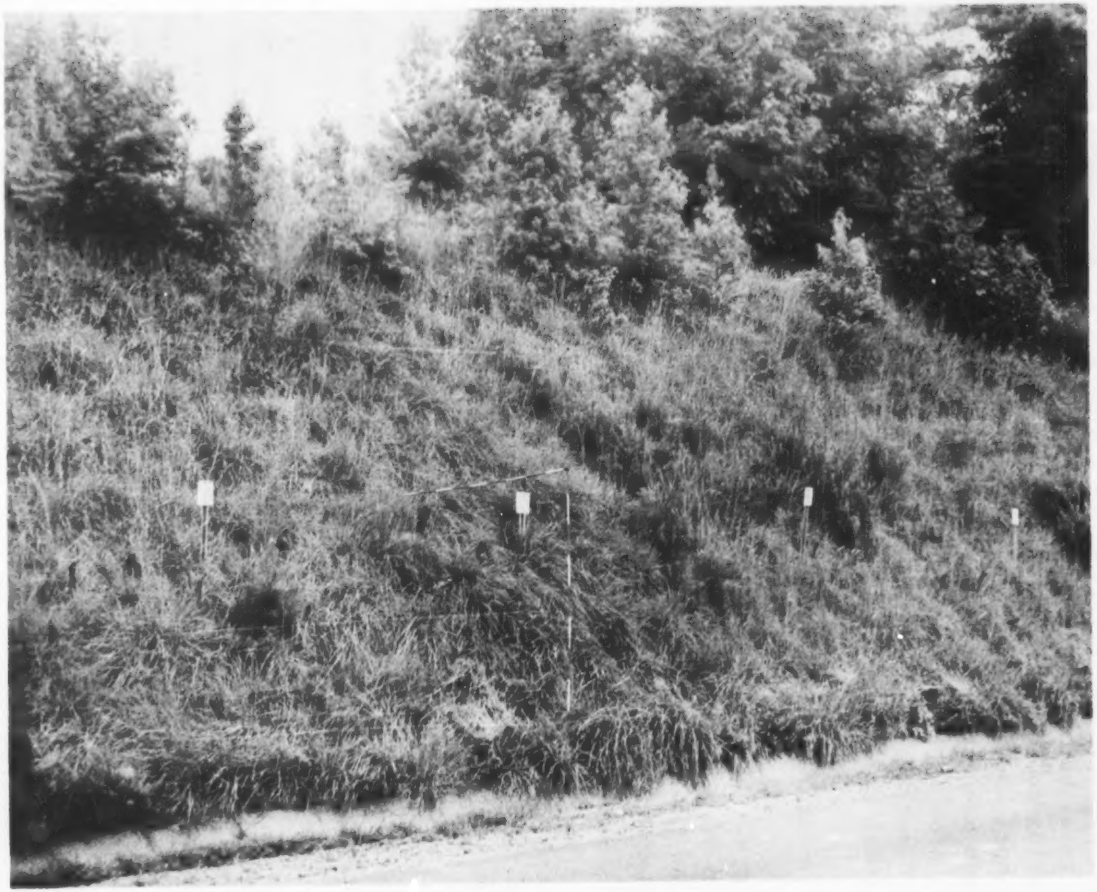

Figure 58 - With no Maintenance Application of Lime and Fertilizer on a Piedmont Plateau 1:1 Slope, Sericea Lespedeza is Crowding Out Kentucky-31 Fescuegrass, and Native Trees and Shrubs are Replacing the Sericea Lespedeza (Courtesy Roy Blaser, Virginia Polytechnic Institute and State University)

6. Additional seeding and fertilization: The application of additional seeding and fertilization is usually essential for obtaining a suitable vegetative cover on steep cut slopes with hard, smooth surfaces. With rough, loose and undulating surfaces one application of fertilizer, seed, and mulch may be adequate. However, when using a total of 1,680 kg/ha (1,500 lb/acre) fertilizer in a single application with a liberal seeding rate, better and more persistent vegetative covers are obtained by splitting the application (two-thirds at seeding, the remainder later). Sunny slopes should usually receive additional applications. Split applications are recommended for seedings made during unfavorable growth periods; also the multi-step principle assures the development of persistent vegetation. The multi-step method allows for reseeding legumes when initial stands are inadequate.

Examples of multi-step applications are:

a. For initial seedings made during spring, apply a second application of fertilizer, seed, and mulch in late summer. If the vegetative cover is unsatisfactory, apply a third treatment the following spring. The retreatments, pending stands of vegetation, may approximate one-half of the initial rates.

b. For initial seedings made during the late summer or early fall, make a second application in the spring. If needed, a third application should be made the following summer.

c. For initial seedings made during winter, make a second application of seed and fertilizer during the next spring if stands are unsatisfactory. Remulch if necessary, also.

7. Sparse vegetation: The common occurrence of unsatisfactory or a degenerating vegetation on cut slope environments in the Piedmont region soon after seeding is now explainable by research findings. Lime was not specified for seeding in highway construction corridors; hence, the acid soil conditions, low calcium, and high soluble aluminum depressed all species used in seeding mixtures, except possibly redtop grass.

Redtop grass is short-lived and not persistent. The low rate of fertilization and the low amount of phosphorus in the 10-6-4 fertilizer, coupled with the acid soil conditions without liming, resulted in a very low availability of phosphorus and inadequate nitrogen. Tall fescue, a hardy persistent grass, was in a developmental stage and had not been used in mixtures; also weeping lovegrass and sericea lespedeza are more recent developments (Figure 59). The poorly adapted grasses used in the mixtures degenerated.

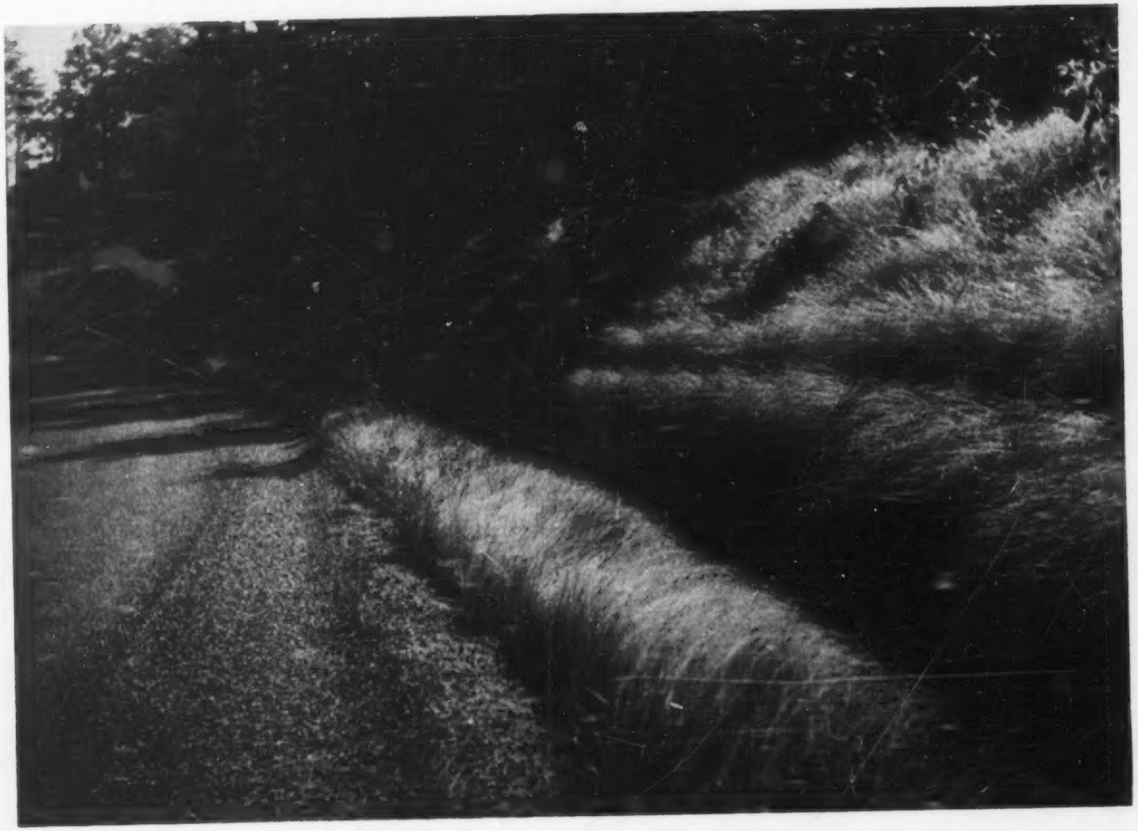

Figure 59 - Weeping Lovegrass has Been Successively Established on a Grooved, 1:1 South Slope in About 2 Months from Time of Summer Seeding (Courtesy Roy Blaser, Virginia Polytechnic Institute and State University)

The improving of the sparse vegetation in the highway corridor was accomplished in two ways. Liberal applications of fertilizers high in N and P_2O_5 (10-20-5) were recommended and used to thicken the sparse vegetative cover to give erosion protection. Later based on research, sericea lespedeza was seeded into sparse stands of grass. This was done before erosion occurred; lespedeza established quickly as the sparse grass and other vegetation did not shade out lespedeza. It was also observed that natural woody vegetation in the absence of mowing encroached naturally to give variable aesthetically desirable persistent vegetative cover.

II. WATERWAY AND DAM PROTECTION

A. Introduction

The construction of ponds or lakes in watersheds to detain the flow of water, and the stabilization of waterways with persistent vegetation can cause deposition of transported sediments and deter erosion, soil depletion and other sediment problems. Clean water stored in the ponds or lakes is useful to industry, agriculture, and local communities of the area.

B. Vegetation Stabilization Procedures

A grassed waterway, pond embankment, and a spillway in Halifax County, Virginia, on the U.S. Plywood Corporation property 2 miles east of South Boston were seeded in early autum 1960 (Figure 56). The project was supervised by personnel of the Soil Conservation Service. The Helena and Wilkes soil series, formed from weathering of mica gneiss and associated rocks, were described as nonfertile, being highly acid in reaction and very low in phosphorus and nitrogen.

The range of channel gradients (percent) and permissible water velocities for various vegetative covers in waterways recommended by the Virginia Soil and Water Conservation Commission (1974) are shown in Table 21.

The pond with embankment and spillway and the jute waterways are shown (Figure 60) soon after seeding with specifications by Virginia Soil and Water Conservation Commission (1974) and Vaden (1966). Specifications for seeding were:

TABLE 21

THE RELATIONSHIPS OF VEGETATION, CHANNEL GRADIENT, AND PERMISSIBLE (NONEROSIVE) VELOCITY OF WATER IN GRASSED WATERWAYS

Vegetative Cover[a]	Range of Channel Gradients (%)	Permissible Velocity of Water ft/sec	Permissible Velocity of Water m/sec
1. Bermuda Grass[b]	0 to 5	6	2
	5 to 10	5	2
	Over 10	4	1
2. Reed Canarygrass Fall Fescuegrass Kentucky Bluegrass	0 to 5	5	2
	5 to 10	4	1
	Over 10	3	1
3. Grass-Legume Mixtures	0 to 5	4	1
	5 to 10	3	1
4. Red Fescuegrass Redtop Sericea Lespedeza	0 to 5	2.5	1
5. Annuals: Annual Lespedeza Small Grains (Rye, Oats, Barley) Ryegrass	0 to 5	2.5	1

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a/ To be used only below stabilized or protected areas.

b/ Recommended varieties of bermuda grass are Tufcote, common, U3, Midland, and Coastal.

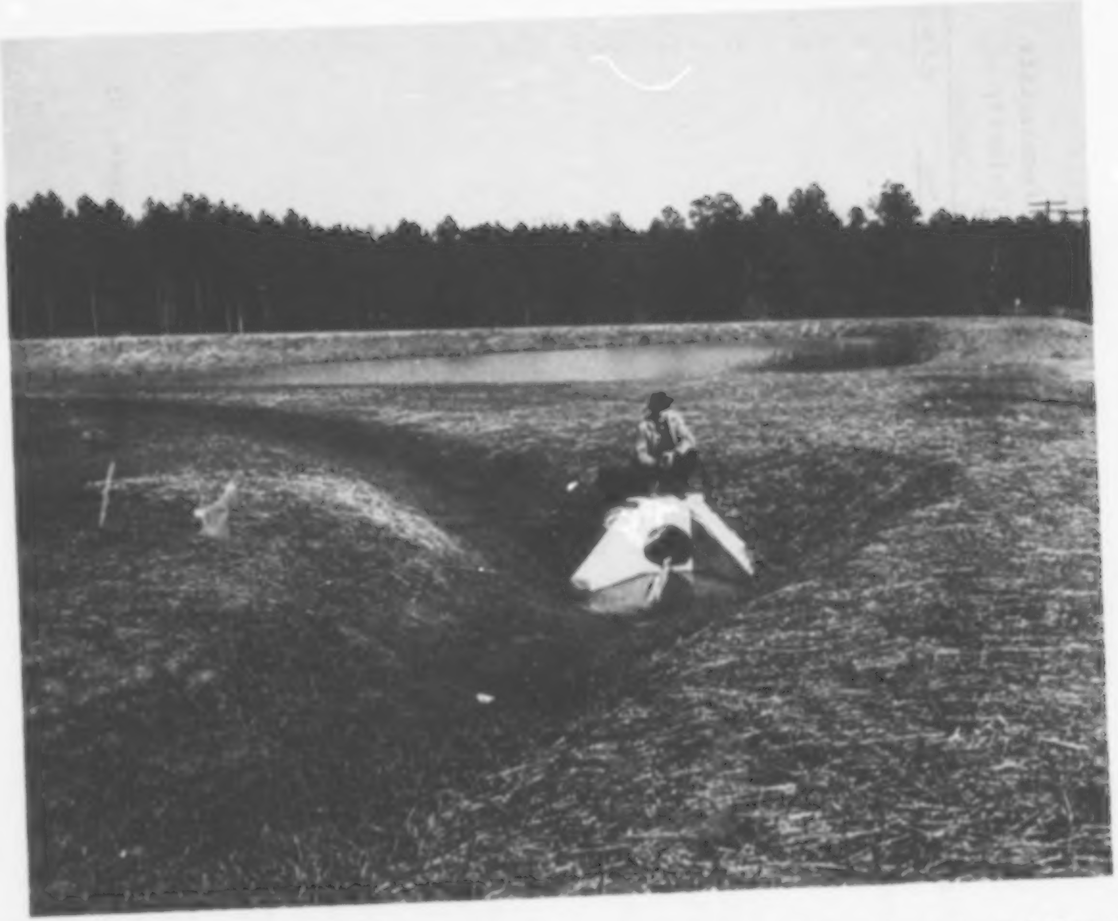

Figure 60 - Erosion Control in Grassed Waterways, Pond Embankments and Spillway in Halifax County, Virginia (Piedmont Plateau). Excellent stands of grass seedlings developed in jute-lined waterways and straw-mulched embankments. Later, excellent vegetative cover resulted from the lime and fertilizer treatments and the adapted Kentucky-31 tall fescuegrass seeding. (Courtesy of Soil Conservation Service)

1. The separate application of 4.5 to 6.7 mt/ha (2 or 3 tons/acre) of finely ground limestone and 1,121 kg/ha (1,000 lb/acre) of 45% triple superphosphate or its equivalent disked in to a depth of 7.5 cm (3 in.). Separately and before the last disking, 1,121 kg/ha (1,000 lb/acre) of a 10-10-10 fertilizer was applied.

2. The seed mixture included about 80 kg/ha (70 lb/acre) of Kentucky-31 tall fescuegrass and 2.2 kg/ha (2 lb) of white clover. Sericea lespedeza at 22 kg/ha (20 lb/acre) was added with spring seedings and overseeded in the spring for seedings made during the autumn.

3. Small grain straw as a mulch was applied at 3.4 to 4.4 mt/ha (1-1/2 to 2 tons/acre) and was anchored either with asphalt emulsion or by a mulch anchoring tool (a cut-away disc set flat that embedded the straw into the soil).

4. The soil was rolled with a corrugated roller before and after seeding; for the jute-lined waterways one-half of the seed was applied before and one-half after laying the jute. Topsoiling is not generally recommended in the Piedmont and was not used for this project.

The jute lining in the waterways was installed as recommended by the Virginia Soil and Water Commission (1974):

1. The waterway was shaped and graded to handle the expected waterflow.

2. All rocks over 3.75 cm (1.5 in.) in diameter and other material were removed, leaving a loose, smooth soil for good mat-soil contact to avoid water movement under the mat.

3. Matting was laid from the top of the channel or slope and unrolled downgrade so that one edge of the strip coincided with the channel center.

4. A second strip of jute matting was laid parallel to the first, on the other side of the channel, with at least a 5-cm (2-in.) overlap.

C. Additional Guidelines

Based upon experience gained in establishing the grassed waterway, and in vegetating the dam and spillway, Joseph Vaden of the Soil Conservation Service recommends these additional procedures:

1. Bury the upper end of the jute strips in a trench 10 cm (4 in.) or more deep. Tamp the trench full of soil. Reinforce with a row of staples driven through the jute about 10 cm (4 in.) downhill from the trench. These staples should be about 25 cm (10 in.) apart. Then staple the overlap in the channel center. These staples should be 90 to 120 cm (3 to 4 ft) apart. The outside edges may be stapled similarly at any time after the center has been stapled.

2. Succeeding strips of matting, farther down the channel or slope, are secured in a similar manner. Where one roll of jute matting ends and another roll begins, the end of the top strip should overlap the trench where the upper end of the lower strip is buried. Make the overlap at least 10 cm (4 in.) and staple securely.

An exceptionally good sod cover of Kentucky-31 fescuegrass developed in waterways, embankments, and on the spillway. White clover failed to make a significant contribution and should be omitted from future seed mixtures. Although sericea lespedeza was not used for waterways, it should be used, as its deep roots resist washouts, and the top growth slows water movement while also bending downhill and causing a "shingling" protective effect.

III. SOURCES OF FURTHER RESOURCE INFORMATION

Department of Agronomy
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061
703-951-6305

Environmental Quality Engineer
Virginia Department of Highways
1221 East Broad Street
Richmond, Virginia 23219
804-770-4304

Halifax County Extension Office
Box 757
Halifax, Virginia 24558
804-476-2895

Highway and Transportation Research Council
Department of Highways and Transportation
Box 3817
University Station
Charlottesville, Virginia 22903
804-977-0290

Soil Conservation Service
Federal Building
400 North 8th Street
P.O. Box 0026
Richmond, Virginia 23240
804-782-2457

IV. ADDITIONAL REFERENCES

Barkley, D. G., R. E. Blaser, and R. E. Schmidt, "Effect of Mulches on Microclimate and Turf Establishment," *Agricultural Journal*, **57**:189-192 (1965).

Blaser, R. E., "Soil Mulches for Grassing," National Academy of Science, Highway Research Board, *Roadside Development*, **1030**:15-20 (1962).

Blaser, R. E., "Principles for Making Up Seed Mixtures for Roadside Seedings," National Academy of Science, Highway Research Board, *Roadside Development*, **1120**:79-84 (1963).

Blaser, R. E., and W. H. McKee, "Regeneration of Woody Vegetation Along Roadsides," *Highway Research Record*, **161**:104-115 (1967).

Blaser, R. E., G. W. Thomas, C. R. Brooks, G. J. Shoop, and J. B. Martin, Jr., "Turf Establishment and Maintenance Along Highway Cuts," Highway Research Board, Washington, D.C., *Roadside Development*, **928**:5-19 (1961).

Blaser, R. E., and C. Y. Ward, "Seeding Highway Slopes as Influenced by Lime, Fertilizer, and Adaptation of Species," Highway Research Board, Washington, D.C., *Roadside Development*, **613**:21-39 (1958).

Blaser, R. E., and J. Woodruff, "The Need for Specifying Two- and Three-Step Seeding and Fertilization Practices for Establishing Sod on Highways," Highway Research Board, Washington, D.C., *Highway Research Record*, **246**:44-49 (1968).

Buol, S. W., Editor, "Soils of the Southern States and Puerto Rico," A Joint Regional Publication by the Agricultural Experiment Stations of the Southern States and Puerto Rico Land-Grant Universities with Cooperative Assistance by the Soil Conservation Service, USDA, 105 pages (1973).

Carson, E. W., Jr., "The Responses of Lespedeza Cuneata to Nitrogen and Grass Associates," Master of Science Thesis, Virginia Polytechnic Institute (1963).

Carson, E. W., Jr., and R. E. Blaser, "Establishing Sericea Lespedeza on Highway Slopes," Highway Research Board, Washington, D.C., Roadside Development, 1030:3-14 (1962).

Green, J. T., Jr., J. M. Woodruff, and R. E. Blaser, "Stabilizing Disturbed Areas During Highway Construction for Pollution Control," Final Report, Agronomy Department, Virginia Polytechnic Institute and State University, 84 pages (1973).

Jurney, R. C., S. O. Perkins, R. E. Devereux, S. S. Obenshain, E. Shulkcum, and G. W. Patterson, "Soil Survey of Halifax County, Virginia," Bureau of Chemistry and Soils, Series 1934, No. 5, 56 pages (1938).

McKee, W. H., R. E. Blaser, and D. W. Barkley, "Mulches for Steep Cut Slopes," Highway Research Board, Highway Research Record, 54:35-42 (1964).

McKee, W. H., Jr., and R. E. Blaser, "Fertilizer Maintenance as Related to Sod Degeneration and Encroachment of Woody Species," Research Report, Virginia Polytechnic Institute Research Division, pp. 28-321 (1967).

McKee, W. H., A. J. Powell, Jr., R. B. Cooper, and R. E. Blaser, "Microclimate Conditions Found on Highway Slope Facings as Related to Adaptation of Species," Highway Research Board, 1309:38-43 (1965).

McKee, W. H., R. E. Blaser, A. J. Powell, R. B. Cooper, U. Yadar, and P. Bosshart, "The Establishing and Maintenance of Vegetation on Various Environments Along Interstate Highways," Annual Report, Virginia Agricultural Experiment Station in cooperation with the Virginia Council of Highway Investigation and Research and U.S. Bureau of Public Roads, 60 pages (1965).

Shoop, G. J., C. R. Brooks, R. E. Blaser, and G. Thomas, "Differential Responses of Grasses and Legumes to Liming and Phosphorus Fertilization," Agricultural Journal, 53:111-115 (1961).

Van Dine, J. W., and W. F. Sledjeski, "Soil Survey of Charlotte County, Virginia," Soil Conservation Service, USDA in cooperation with Virginia Polytechnic Institute and State University, 97 pages (1974).

Woodruff, J. M., J. T. Green, and R. E. Blaser, "Weeping Lovegrass for Highway Slopes in the Virginias," Highway Research Board, Washington, D.C., Highway Research Record, 411:7-14 (1972).

Woodruff, J. W. and R. E. Blaser, "Establishing Crownvetch on Steep Slopes in Virginia," Highway Research Board, Washington, D.C., Highway Research Record, 335:19-28 (1970).

Vaden, J. H., "Vegetative Protection for Water Storage in Virginia," presented at the Annual Meeting of the Soil Conservation Society of America, Albuquerque, New Mexico, 15-17 August 1966.

"Virginia Erosion and Sediment Control Handbook," Virginia Soil and Water Conservation Commission, P.O. Box 1163, Richmond, Virginia 23209, April 1974.

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MASSACHUSETTS--DEMONSTRATION AREA NUMBER 9

ROADSIDE VEGETATION

Summary

Massachusetts is characterized by cool temperatures, a humid moisture regime throughout the year, and acid soils of low fertility. The soils are classified in the extensive Great Group of Haplorthods. Soil tests have invariably indicated a need for lime, nitrogen, phosphorus, and potassium fertilizers. Recommended seeding mixtures vary with the decision to mow or not to mow. In general, shrubs are favored over grasses because the area is a forest and shrub environment. Shrubs that are capable of fixing atmospheric nitrogen through symbiosis are preferred.

Research results documented throughout the State of Massachusetts in this manual include a comparison of woody plant species near Gardner, Walpole, and Merrimac; variable mulches and fertilizers on the growth of Hertz juniper near Erving; and a comparison of dates of seeding for crownvetch near the town of Granville (Figure 61).

I. INTRODUCTION

The State of Massachusetts lies at a latitude mostly north of the 42nd parallel. Except for Cape Cod, adjacent coastal areas, and the Connecticut River Valley, Massachusetts is hilly to mountainous, with elevations mostly between 152 and 610 m (500 and 2,000 ft).

The climate is variable due to the fact that it lies in the storm path of the prevailing westerly winds that cross the United States and encircle the world at middle latitudes. The winds may be cold and dry from the Arctic region or warm and moist from the Gulf of Mexico. Variability of climate is also due to the proximity of the Atlantic Ocean and differences in elevation within the State. During summer when the westerly winds are weak, gentle ocean breezes often blow from the east.[1/]

[1/] "Climates of the States, Vol. I, Eastern States," National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 480 pages, pp. 175-191 (1974).

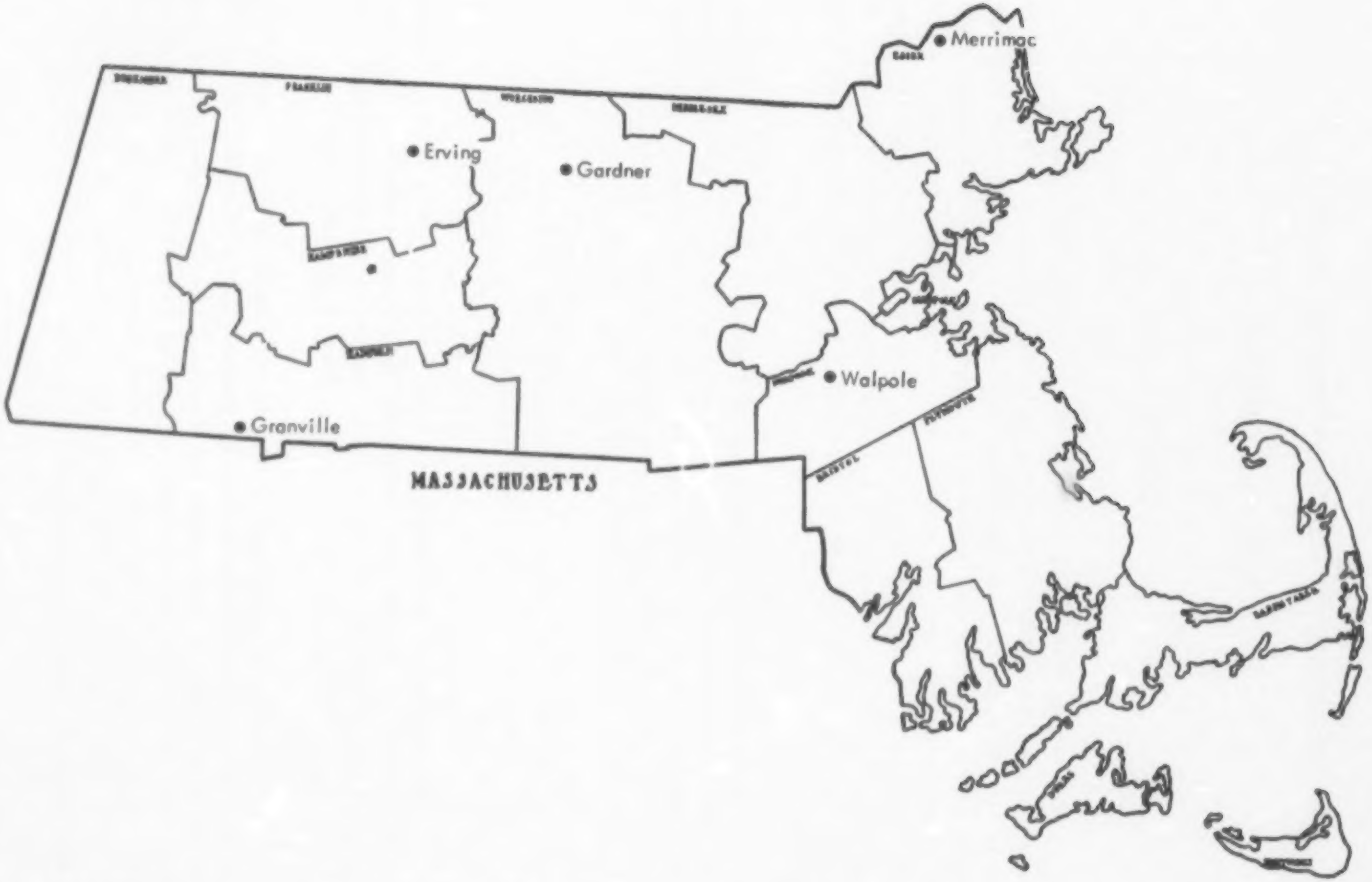
Merrimac
Erving
Gardner
Walpole
Granville
MASSACHUSETTS

Figure 61 - Locations Where Research Results are Documented as Discussed in the Summary

Average annual temperatures vary from 8°C (46°F) in the western mountains to 9°C (49°F) in the central hills to 10°C (50°F) near the Atlantic Coast. The highest temperature on record was 41°C (106°F) and the lowest -37°C (-24°F). The growing season varies from 120 to 200 days. These temperatures place the State of Massachusetts in "Plant Hardiness Zone 5" -29° to -23°C (-20 to 10°F). The State is also placed mostly in Plant Growth Region 27 (See Section III).

Precipitation averages from 102 to 127 cm (40 to 50 in.) a year, and monthly means are between 8 and 10 cm (3 and 4 in.). Droughts are extremely rare with most monthly totals of rainfall varying from 50 to 200% of normal. At least 0.03 cm (0.01 in.) of precipitation falls on an average of 1 day in three. Intensity of rainfall is normally mild; however, the heaviest is received during summer thundershowers. Snowfall varies directly with elevation and ranges between 64 to 203 cm (25 to 80 in.) a year. The number of days with fog varies from 15 to 100, and the number of clear days per year is between 90 and 120. Percentage of possible sunshine is from 45 to 60. Relative humidity is usually high, with monthly means mostly 60 to 80%.

Climatic factors favorable for the establishment of adapted vegetation are the high relative humidity, the even distribution of precipitation each month of the year, and the moderate accumulation of snowfall that protects plants from extremes of temperature. Unfavorable climatic factors for establishing vegetation are glaze ice formation, frost heaving, and occasional hailstorm, and an occasional summer drought. Ice storms that produce glaze on vegetation is a deterrent to successful establishment and maintenance of plants, especially woody plants, on disturbed soils. Another climate-related restraint to vegetation establishment is "heaving" of plants. This phenomenon consists of the formation of ice crystals near the roots and crown of plants and the growth of such crystals from the bottom. The net result is that plants are forced out of the ground with the ice crystals where their roots desiccate and die.

A serious constraint on the successful establishment of vegetation on roadsides and other disturbed soils is the low fertility acid soil conditions and low water-holding capacity of the soils. The latter limitation, however, is ameliorated by the uniform distribution of adequate precipitation, coupled with high relative humidity.

The ecological environments of climate and soil in the State of Massachusetts are conducive to tree and shrub vegetation. To establish and maintain grasses and legumes on roadsides in such an environment requires the application of lime every 3 to 5 years to maintain the soil pH at about 6.5 and fertilizer to raise the levels of N, P, and K perhaps five times above their present levels. Periodic mowing is necessary for maintaining grasses and legumes. Most of the research results reported here will therefore relate to shrubs.

II. SOILS

The soil order of Spodosols is the predominant soil in all six New England States as well as in northern Wisconsin, northern Michigan, and northeastern New York. The most extensive soil Great Group of the Spodosols is Haplorthods, comprising 297,020 km^2 (114,680 miles^2)--3.2% of the land area of the United States.

Undisturbed Haplorthods are well-drained soils characterized by the presence of a strongly acid organic layer 5 to 10 cm (2 to 4 in.) thick underlain by a light gray sandy (albic) horizon of comparable thickness, resting on a dark brown horizon consisting principally of amorphous organic matter plus aluminum, and sometimes iron. All horizons are strongly acid to medium acid, low in lime, and low in essential plant nutrients. Haplorthods are moist throughout the year and throughout the profile except that they may be dry for less than 45 days a year. The soil temperature regime of Haplorthods consists of a mean annual temperature at a 50-cm (20-in.) depth of less than 8°C (47°F), and a difference in mean annual temperature of winter and summer at this depth of more than 5°C (9°F). Entic Haplorthods is the soil family to which all 13 soil series belong that are discussed here in relation to establishing vegetation on roadsides in Massachusetts.

The relatively cool temperature, acid reaction, and small reserve of available essential elements in Haplorthods make the establishment of vegetation difficult. In contrast, the moist soil profile during most of the year favors vegetation establishment. Annual precipitation of 102 to 127 cm (40 to 50 in.) falling as gentle rain or snow, and high humidity because of the proximity to large bodies of water, assure more infiltration, low evaporation, and low transpiration.

III. GRASSES AND LEGUMES

Where grasses and legumes are to be used to vegetate highway cuts, fills, and medians it is necessary to follow these guidelines if successful establishment is expected:

1. Divert excess surface water from the planting site by diversion terraces above the slopes and, on long slopes, at recommended intervals.

2. Protect the area from fire, grazing, and trampling by people.

3. Shape the final grade to a 3:1 slope or flatter.

4. Make a seedbed 10 to 15 cm (4 to 6 in.) deep and leave the surface rough enough to provide a good medium for seed germination.

5. Send a representative soil sample to a chemical soil testing laboratory.

6. Add whatever lime is recommended according to soil test results, for the particular grass-legume mixture specified. Mix the lime with the soil to the depth of the seedbed.

7. Add the amount and kind of chemical fertilizer indicated by the soil test and mix to seedbed depth. (Do not permit lime and fertilizers to come in contact with each other because of loss of nitrogen).

8. Seed the grass-legume mixture with a specialized grass seed drill, if the slopes permit; if not, use a hand seeder and rake seed into the soil. A hydroseeder is also satisfactory (Figures 62 and 63). If the area is to be mowed, the most commonly recommended grasses and legumes are red fescuegrass, fine leaf fescuegrass, Durar hard fescuegrass, tall fescuegrass, annual ryegrass, weeping lovegrass, ladino clover, and alsike clover. If no mowing is planned, perennial ryegrass, red fescuegrass, and crownvetch are recommended.[1] Black

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[1] Hottenstein, W. L., "Highway Roadsides," In: Turfgrass Science, A. A. Hanson, and F. V. Juska, editors, American Society of Agronomy, Madison, Wisconsin, 715 pages, pp. 603-637 (1969).

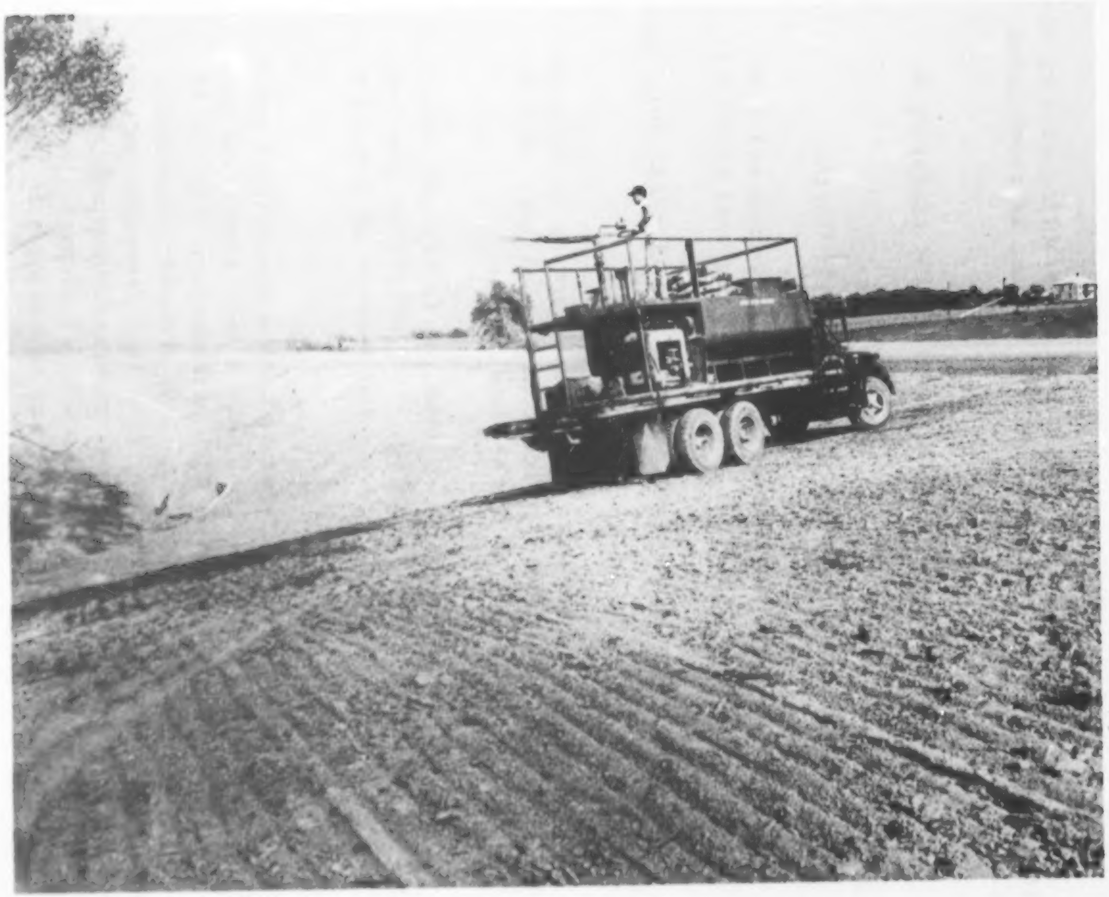

Figure 62 - A Hydroseeder Spreading a Mulch and Seed Slurry on a Fill Slope on Route 81 South of Winchester, Massachusetts (see Figure 63)
(Courtesy of University of Massachusetts)

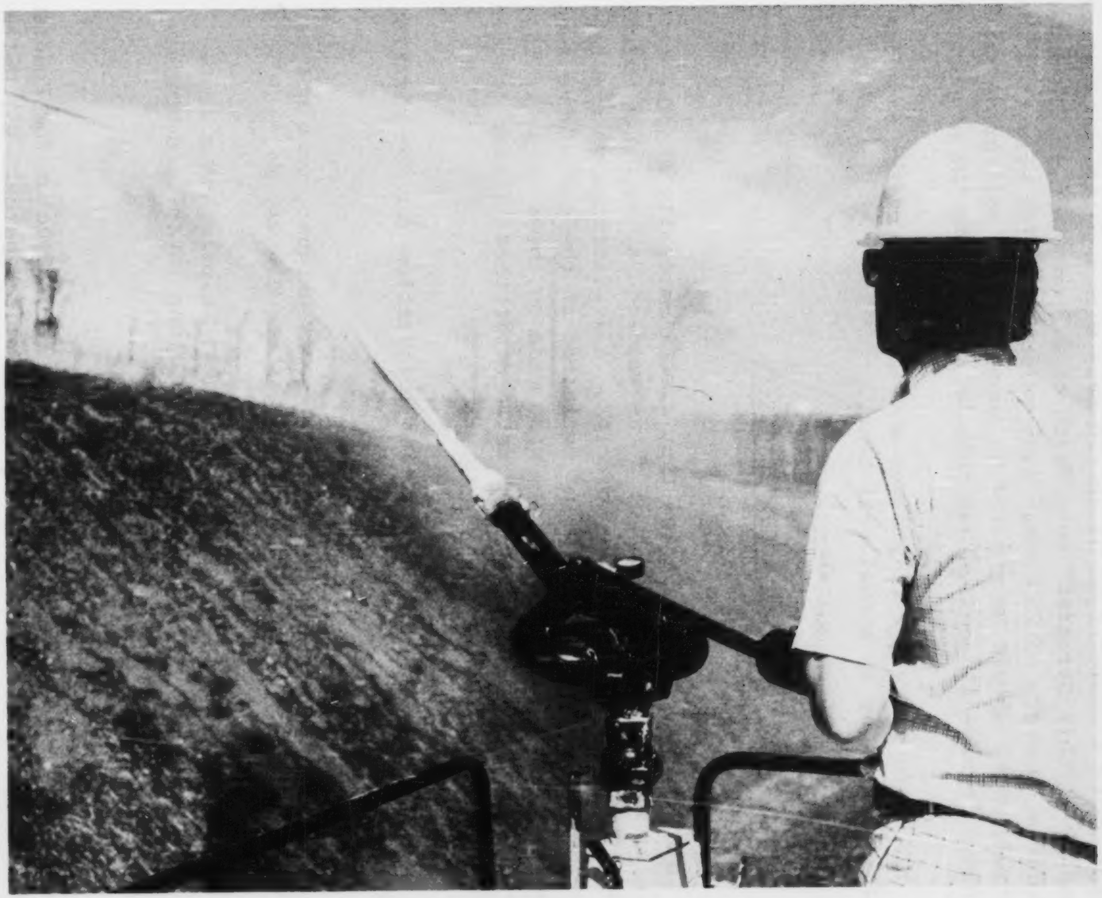

Figure 63 - A Close-Up of the Same Kind of Hydroseeding Operation as in Figure 62, on Route 659 Near Harrisonburg, Massachusetts (Courtesy of University of Massachusetts)

locust can also be established from seed, along with the grasses, but only away from the road.[1]

9. Add the recommended amount and kind of mulch. In Massachusetts woodchips are usually the most suitable. Woodchips can be made from nearby whole trees up to a diameter of 51 cm (20 in.) with a "Total Chipharvester" and spread by a "Chip Spreader" to a depth of 2.5 cm (1 in.). This depth will involve a quantity of 255 m/ha^2 (135 yd/acre^2). For effective sediment control, mulch should be applied as soon as final soil grade has been established. Permanent seedings can then be made during the proper season.

10. Maintain vigor of grasses and legumes by adding any lime fertilizer as directed by an annual soil test.

IV. WOODY PLANTS[2]

Eleven woody plant species that are climatically adapted to Massachusetts were planted on each of three roadside sites, then mulched with 7.5 to 10 cm (3 to 4 in.) of woodchips. All plantings were established during May and June of 1970 and evaluated at the end of the second growing season in 1971. The plantings were made on three moist soils series belonging to the soil family of Entic Haplorthods (least fertile), sandy, mixed, mesic.

Location, slope, and soil series information for the plantings are as follows:

1. Central northern Massachusetts near Gardner, on a north-facing 2:1 fill slope of Charlton loam along State Highway No. 2.

2. Central eastern Massachusetts near Walpole, on a west-facing 2:1 cut slope of Gloucester loamy sand along Interstate Highway 95.

---

[1] Zak, J. M., et al., "The Rise of Adaptable Plant Species for Roadside Cover in Massachusetts," Roadside Development Report 23-R5, University of Massachusetts, Amherst, prepared for the Massachusetts Department of Public Works and the U.S. Department of Transporation, Federal Highway Administration, 160 pages, February 1972.

[2] Zak, J. M., J. Troll, and L. C. Hyde, "Direct Seeding of Woody Plant Species Under a Wood Chip Mulch Along Highways," Roadside Development Report 21, December 1971.

3. Northeastern Massachusetts near Merrimac on an east-facing 2:1 cut slope of Merrimac sandy loam along Interstate Highway 95.

The 11 woody plant species used were:

1. Autumn olive;
2. Bayberry;
3. Bearberry;
4. Bittersweet, oriental;
5. Cedar, red;
6. Indigo bush;
7. Inkberry;
8. Larch, Japanese;
9. Locust, bristly;
10. Plum beach; and
11. Sweet fern.

Survival percentage was highest for most species on the north-facing fill slope on Charlton loam near Gardner. There are three reasons for this:

1. North slopes are more moist and cooler than other aspects. Also, plants on these slopes are slower to start growth in early spring and therefore, are not injured as much by frost.

2. Soils on fill slopes are usually deeper, more fertile, and more moist than the materials on cut slopes. The additional water comes from highway runoff.

3. Charlton loam on the fill slope contains more silt-plus-clay than Gloucester loamy sand or Merrimac sandy loam in the cut slopes. The additional fines supply more nutrients and provide better water/air relations to the plant root zone.

Very little growth of any species occurred the 1st year; but during the second growing season, all species grew well. Autum olive, bayberry, beach plum, bearberry, bristly locust and indigo bush grew more rapidly on the Merrimac sandy loam than on the Gloucester loamy sand or Charlton loam.

Because of their slow growth on all three sites, beach plum and bearberry are not recommended on any upland sites away from coastal areas. Previous research at the University of Massachusetts has indicated that both species are ecologically well adapted to low elevations along the Atlantic Ocean, especially on Cape Cod.

Bristly locust and indigo bush are legumes and, as with all legumes, have the characteristic of fixing atmospheric nitrogen in symbiotic relationships with specific bacteria. Certain nonlegumes also possess this valuable characteristic. Included in this research were autumn olive, bayberry, and sweet fern, which, although not legumes, have the ability to fix atmospheric nitrogen in symbiosis with specific bacteria.

The 8- to 10-cm (3- to 4-in.) layer of woodchips that was spread on all three planting sites provided excellent erosion control. They were expected to be effective until the woody plants got large enough to protect the soil against surface erosion.

V. MULCHES AND FERTILIZERS

A 3-year experiment was conducted to test four kinds of mulches and four fertilizers on the growth of Hertz juniper. The site was a south-facing 4:1 cut slope of Gloucester sandy loam on State Highway No. 2 near Erving, Massachusetts, in the central northern part of the State.

The mulches were:

1. Hay at the rate of 2.2 mt/ha (1 ton/acre).

2. Fiberglass mat, 6 mm (1/4 in.) thick and 1 m^2 (1 yd^2), slit to the center and placed around each Hertz juniper plant. Hay mulch was placed between the fiberglass mats to cover the slope completely.

3. Woodbark to a depth of 5 cm (2 in.).

4. Woodchips to a depth of 5 cm (2 in.).

Within each mulch treatment there were five randomized fertilizer treatments, each replicated 10 times. The four fertilizer treatments were:

1. Bone meal (2-27-0) at the rate of 5.4 kg/m^2 (10 lb/yd^2).

2. Slow-release water-soluble fertilizer (16-8-6) in a permeable plastic packet weighing 56.7 g (2 oz); "Eeesy-grow" used at the rate of one packet per plant.

3. Slow-release fertilizer (20-10-5) in a tablet weighing 21 g (Agriform), used at the rate of one tablet per plant.

4. Water-soluble liquid fertilizer (Fer-mel) (18-18-18), used at the rate of 50 ml/plant (1 pt/plant) of a mixture of 6 kg of fertilizer in 1,000 liters (5 lb of fertilizer in 100 gal.) of water.

5. Control (no fertilizer).

Survival of all plants was excellent. Growth during the 1st year was slow on all treatments. At the end of the third growing season, these conclusions were made:

1. Woodbark was superior to other mulches, as measured by height and diameter growth of the test plant, Hertz juniper.

2. Woodchips were almost as desirable as woodbark (Figures 64 and 65).

3. Fiberglass with mat-hay mulch produced plants that were slightly better than those with hay alone, but the difference was not significant.

4. Hay alone was the least effective mulch, probably because of the weed seeds in the hay.

Plants given the slow-release 20-10-5 tablet of Agriform were superior in height to those receiving other fertilizers. Next in response were plants that received the slow-release 16-8-6 "Eeeasy-grow" plastic packet, bone meal, water-soluble 18-18-18 liquid, and control (no fertilizer).

VI. CROWNVETCH

Crownvetch is a sprawling herbaceous legume with a profusion of pink flowers that has a very wide climatic adaptation to Plant Hardiness Zones 3, 4, 5, 6, and 7 (see Section III). It will grow on dry, infertile soils on road cuts but grows best on well-drained fertile materials soil. Crownvetch will not thrive on wet or strongly acid soils. It grows to a height of 30 to 60 cm (12 to 24 in.). Roots are perennial but the tops die each winter and mat down to form a protective soil mulch during the dormant season. Propagation is by crowns and seeds.

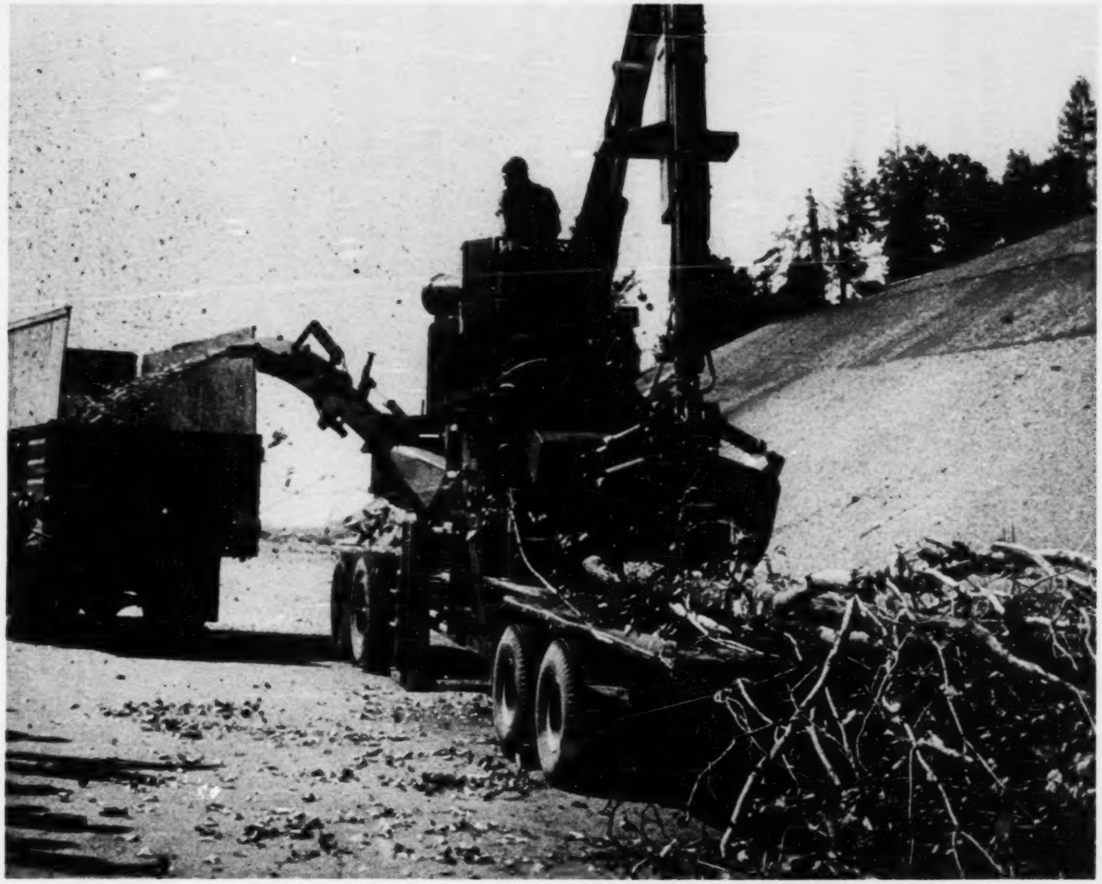

Figure 64 - In Wooded Areas Such as Massachusetts, Local Trees and Shrubs Can Readily be Chipped for Use as a Mulch to Stabilize Surface Slopes Until Perennial Vegetation is Well Established (Courtesy of John Zak, University of Massachusetts)

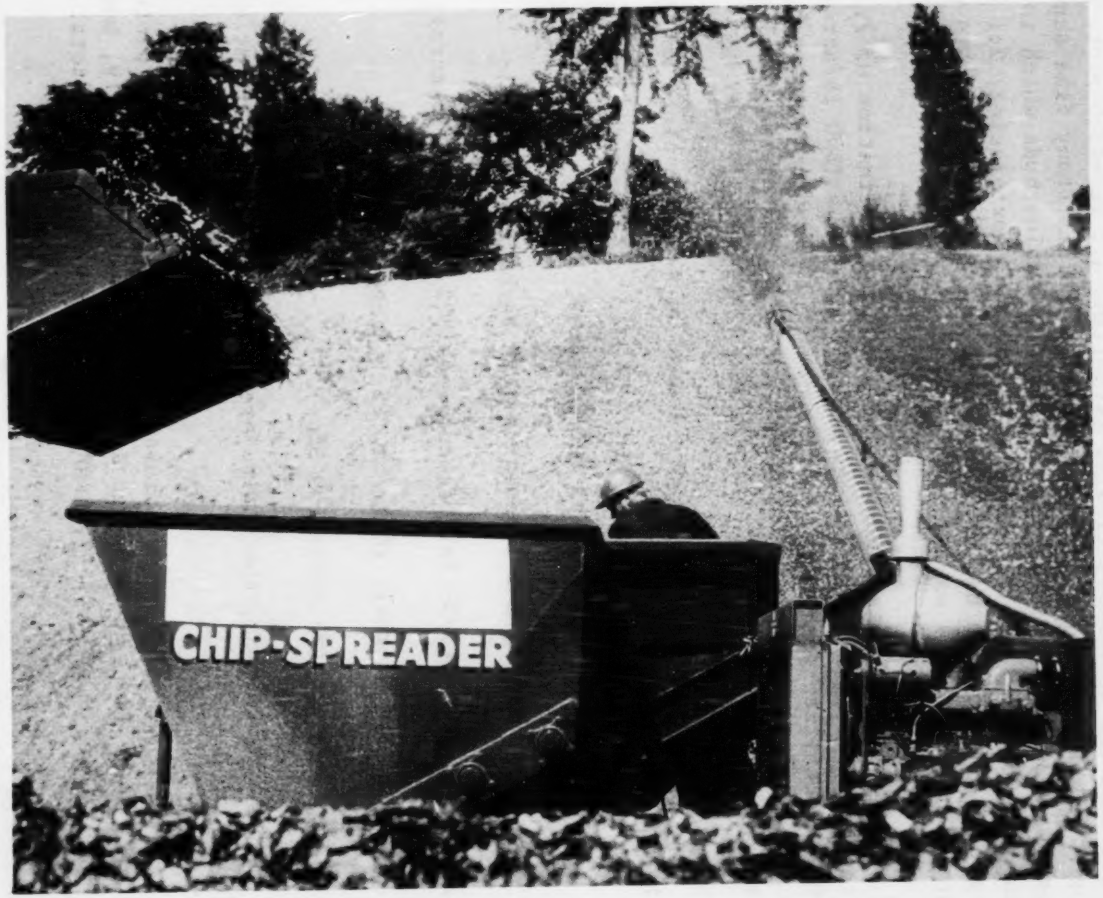

Figure 65 - Woodchips and Woodbark Can be Spread Uniformly by a Mechanical Spreader on Construction Slopes (Courtesy of John Zak, University of Massachusetts)

Seeds are often so slow in germinating that crownvetch does not become well-established during the most critical season, which is immediately after construction activities have been conducted. Once established, however, crownvetch is vigorous and aggressive and therefore an excellent perennial for ground protection and sediment control. To overcome the deficiency of slow establishment, research plots with several companion crops were established on Hollis stony fine sandy loam, a member of the family of Entic Lithic Haplorthods which is loamy and moist. The plots were on a roadside, west-facing, 2:1 cut slope, 17 m (55 ft) in height, in central northern Massachusetts near Granville. No topsoil was applied.

The treatments consisted of a uniform application of 2.2 mt/ha (1 ton/acre) of agricultural limestone and 900 kg/ha (800 lb/acre) of 0-20-20 fertilizer per acre. On 11 December 1968, the crownvetch (variety Penngift) was inoculated with the appropriate bacteria, hand seeded at the rate of 20 kg/ha (18 lb/acre), and covered lightly by hand raking.

Companion crops that were seeded in separate plots and their seed rate per acre comprised:

1. Ryegrass, 22 kg/ha (20 lb/acre);
2. Creeping red fescuegrass, 22 kg/ha (20 lb/acre);
3. Kentucky-31 tall fescuegrass, 22 kg/ha (20 lb/acre);
4. Rye, cereal, 28 kg/ha (25 lb/acre); and
5. Check (no companion crop).

After seeding, the entire area was mulched with 2.2 mt/ha (1 ton/acre) of hay.

All companion crops germinated quickly and formed a protective cover for the soil. The crownvetch developed much more slowly, but at the end of the 3rd year it represented from 85 to 98% of the total ground cover.

Based upon other research by the University of Massachusetts, the best seeding date for crownvetch is April to July, and the second best months are November and December. Other research in all highway districts of Massachusetts on seven soil series indicated that crownvetch can be established most quickly with potted plants (one plant per 3 in. peat pot). Reproduction by bare-root crowns was second best, by a comparison of 92 to 76% survival, respectively.

VII. SOURCES OF ASSISTANCE

Bureau of Transportation, Planning and Development
Massachusetts State Department of Public Works
100 Nashua Street, Morton Building
Boston, Massachusetts 02114

Commissioner of Agriculture
100 Cambridge Street
Boston, Massachusetts 02202
617-727-3000

Department of Plant and Soil Sciences
College of Food and Natural Resources
University of Massachusetts
Amherst, Massachusetts 01002
415-545-2243

Director, Agricultural Experiment Station
University of Massachusetts
Amherst, Massachusetts 01002
413-545-2771

Director of Extension
Univeristy of Massachusetts
Amherst, Massachusetts 01002
413-545-2666

Massachusetts Association of Conservation Commissions
506 Statler Office Building
Park Square
Boston, Massachusetts 02116
617-542-1584

Massachusetts Association of Conservation Districts
211 Westboro Road
Grafton, Massachusetts 01536
617-839-5301

Northeastern Forest Experiment Station
U.S. Forest Service
6816 Market Street
Upper Darby, Pennsylvania 19082
215-352-5800

State Conservationist
Soil Conservation Service
27-29 Cottage Street
Amherst, Massachusetts 01002
413-549-0650

VIII. ADDITIONAL REFERENCES

"Grass," The Yearbook of Agriculture, U.S. Department of Agriculture, 892 pages (1948).

Hanson, A. A., and F. V. Juska, "Turfgrass Science," Monograph No. 14, American Society of Agronomy, Madison, Wisconsin, 715 pages (1969).

Havis, J. R., and W. W. Hamilton, "An Evaluation of Planting Methods for Liner-Size Plants on a Highway Slope," Roadside Development Report 18, May 1971.

Heath, M. E., D. S. Metcalfe, and R. F. Barnes, Forages--The Science of Grassland Agriculture, Iowa State University Press, Ames, Iowa, 755 pages (1973).

Jonsson, G. B., J. Troll, S. O. Odurupwe, L. C. Hyde, and J. M. Zak, "Direct Seeding of Shrubs Along Roadsides in Massachusetts," Roadside Development Report 39-R5-2656, University of Massachusetts, prepared for Massachusetts Department of Public Works in cooperation with the U.S. Department of Transporation, Federal Highway Administration, 10 pages, December 1974.

"Landscape for Living," The Yearbook of Agriculture, U.S. Department of Agriculture, 376 pages (1972).

Seymour, E. L. D., The Wise Garden Encyclopedia, Grosset and Dunlap, New York, 1,380 pages (1970).

"Soil Series of the United States, Puerto Rico, and the Virgin Islands: Their Taxonomic Classification," Soil Conservation Service, U.S. Department of Agriculture, 361 pages, August 1972.

Walsh, L. M., and J. D. Beaton, "Soil Testing and Plant Analysis," Soil Science Society of America, Madison, Wisconsin, 491 pages (1973).

Zak, J. M., et al., A Handbook for the Selection of Some Adaptable Plant Species for Massachusetts Roadsides, Roadside Development Report 24-R5-2656, University of Massachusetts, prepared for Massachusetts Department of Public Works in cooperation with U.S. Department of Transportation, Federal Highway Administration, 160 pages, February 1972.

Zak, J. M., and P. A. Kaskeski, "Crownvetch for Roadside Cover in Massachusetts: Time of Seeding," Roadside Development Report 15, July 1970.

Zak, J. M., and P. A. Kaskeski, "Effects of pH and Soil Fertility on Seeding Establishment on Crownvetch in Massachusetts," Roadside Development Report 9, October 1968.

Zak, J. M., J. Troll, and L. C. Hyde, "Direct Seeding of Woody Plant Species Under a Wood Chip Mulch Along Highways," Roadside Development Report 21, December 1971.

ALASKA

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ALASKA--DEMONSTRATION AREA NUMBER 10

SOILS VEGETATING IN CENTRAL ALASKA ALONG THE ALASKAN PIPELINE

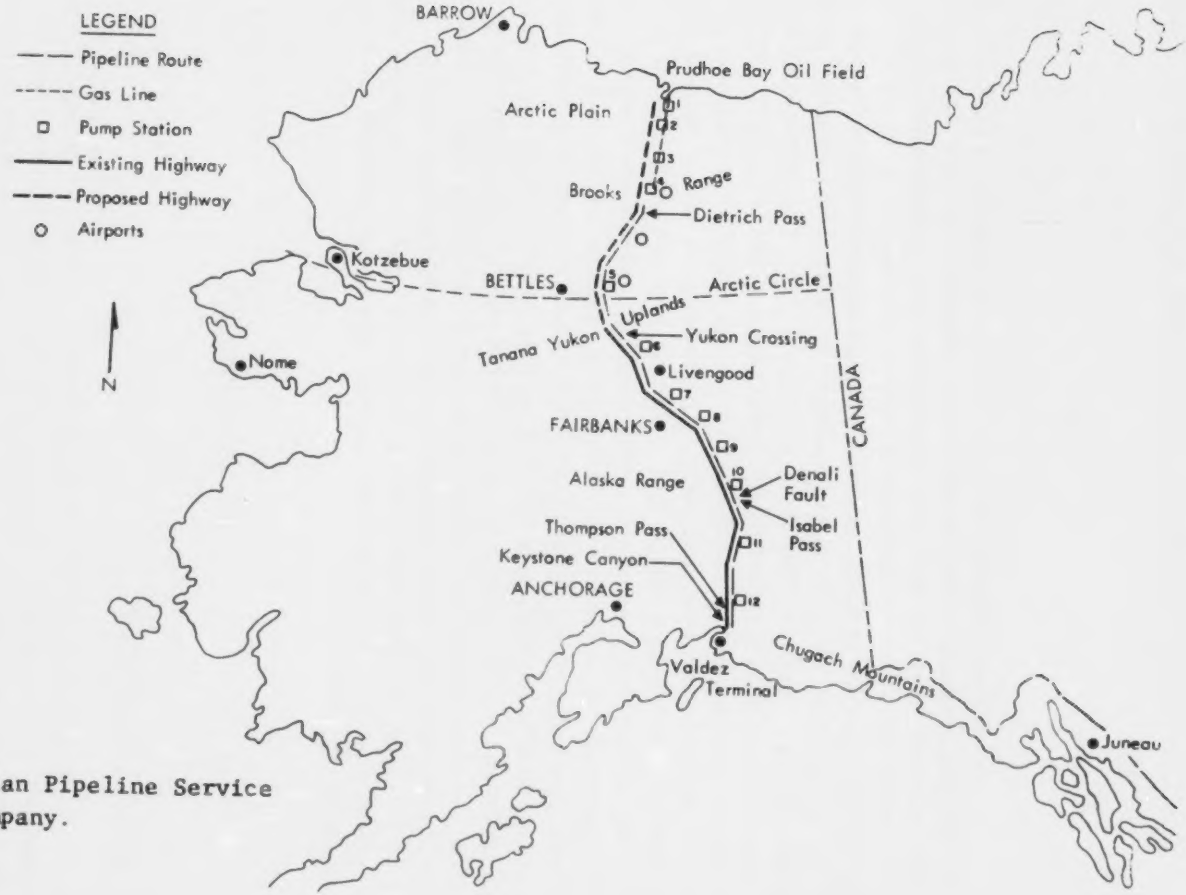
Summary

In central Alaska astride the Artic Circle, the 1,270 km (789-mile) Alaskan pipeline and an adjacent service road are being built. In the central half of this pipeline route the predominant soils belong to the Great Group of Cryaquepts (cold), comprising 9.9% of the land area of the United States. Annual precipitation averages about 25 cm (10 in.), but the area is humid because of very low evaporation and transpiration. Freeze-free days average 65 to 115, depending mostly on elevation. Soil disturbed by construction activities along this stretch of the pipeline is liable to be very unstable because of buried ice lenses (permafrost) that melt. Depending on the size and shape of ice lense, the surface water and sediment may move rapidly down the slope or it may move straight down, causing caverness erosion. It is very important to maintain an insulating organic cover on the soil to prevent the underlying permafrost from thawing. Exposed soil must be covered quickly to reduce excessive melting and subsequent erosion and high sediment yield. Types of soil cover may be the natural surface organic layer, straw, hay, woodchips, or a synthetic mat. Liming and fertilizing must be based on a soil test, seeding must be done between May 15 to June 15, and the seeding mixtures must include only cold-resistant plants. Specified herbaceous and woody groundcover are also recommended.

I. INTRODUCTION

A. Demonstration Area

The demonstration area chosen in Alaska to document examples of successful procedures for establishing vegetation on specific sites lies along the central sector of the route of the Alaskan pipeline. The entire pipeline extends from the new oil fields at Prudhoe Bay southward for a distance of 1,270 km (789 miles) to the Pacific Ocean warm-water port at Valdez (Figure 66).


LEGEND
Pipeline Route
Gas Line
Pump Station
Existing Highway
Proposed Highway
Airports
N
BARROW
Prudhoe Bay Oil Field
Arctic Plain
Brooks Range
Dietrich Pass
Kotzebue
BETTLES
Arctic Circle
Uplands
Yukon Crossing
Tanana Yukon
Nome
Livengood
FAIRBANKS
CANADA
Alaska Range
Denali Fault
Isabel Pass
Thompson Pass
Keystone Canyon
ANCHORAGE
Valdez
Terminal
Chugach Mountains
Juneau
1
2
3
4
5
6
7
8
9
10
11
12

Source: Alaskan Pipeline Service Company.

Figure 66 - Details Along the Alaskan Pipeline from Prudhoe Bay Oil Fields to Valdex, a Warm-Water Port on the Pacific Ocean, a Distance of 789 Miles

Geographically, the route of the Alaskan pipeline follows approximately along the meridian of longitude 150 degrees west and at a range between 61 degrees north and 70 degrees north latitude. The Artic Circle, at 66-2/3 degrees north latitude is, therefore, slightly north of the center of the route. The City of Fairbanks is in the center of the demonstration area.

The northern terminus of the Alaskan pipeline starts at Prudhoe Bay, a 78-km^2 (30-$mile^2$) perpetually wet area that lies at elevations between sea level at the Beaufort Sea in the Artic Ocean, to about 183 m (600 ft) on the north slope of the Brooks range of mountains. Here, annual precipitation is only 4 in. a year, falling mostly as snow. Only 42 days a year have mean temperatures above freezing and there are no days when the mean daily temperature is 21°C (70°F) or above. The number of hours of sunlight on June 22 is 24; i.e., the sun never sets. On December 22, the sun never rises above the horizon.

Figure 66 is an outline map of Alaska that shows the approximate location of the Alaskan pipeline route, with some of the geographic locations indicated. Figure 67 is a map on which is demarcated the soil and site groups used as the basis for seeding and fertilizing recommendations. The part of the area delineated as "Interior Area" includes the demonstration area. Within this area are six seeding recommendations made for contrasting soils. Only soil Groups 4 and 5 are classified within the soil Great Group of Cryaquepts, and for this reason the recommendations for only these two groups are given here. For recommendations for the other site groups in Alaska, read "A Vegetative Guide for Alaska."[1]

From the Brooks range of mountains on southward to within a few miles of Valdez, the land is rolling and often mountainous. The most difficult topography for the pipeline to cross will be the Endicott Mountains, the Ray Mountains, the Yukon River near the Artic Circle, the Alaska Range, the Thompson Pass and the Keystone Canyon in the Chugach Mountains not far from Valdez.

Snowfall is the principal form of precipitation in this central region. Thompson Pass, the route of the Alaskan pipeline at the southern

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[1] Cooperative Extension Service, "A Vegetative Guide for Alaska," University of Alaska, M7-N-22612, 50 pages (1972).

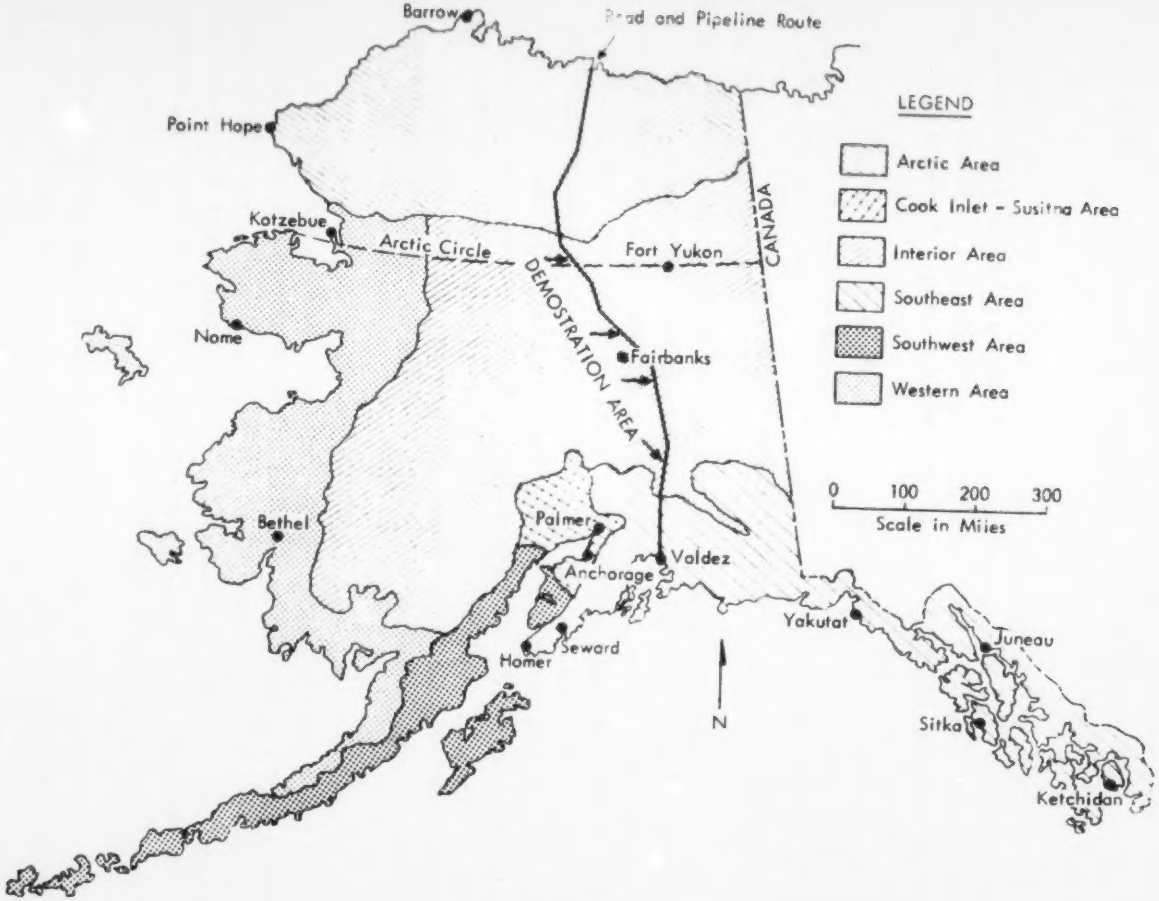
Barrow
Road and Pipeline Route
Point Hope
Kotzebue
Arctic Circle
Fort Yukon
CANADA
DEMONSTRATION AREA
Nome
Fairbanks
Bethel
Palmer
Anchorage
Valdez
Seward
Homer
Yakutat
Juneau
Sitka
Ketchidan
N
LEGEND
Arctic Area
Cook Inlet - Susitna Area
Interior Area
Southeast Area
Southwest Area
Western Area
0
100
200
300
Scale in Miles

Figure 67 - Demonstration Site No. 10 in Central Alaska

end of the central region, has all of Alaska's snowfall records, which are as follows:[1]

Maximum for one season (1952-1953) - 2,476 cm (974.5 in.)
Maximum monthly record (February 1953) - 757 cm (298 in.)
Maximum 24-hr record (December 1955) - 157 cm (62 in.)

For this report the demonstration area consists of the soil Great Group of Cryaquepts that occurs within this central region.

Mean annual total hours of sunshine along the route of the pipeline is about 2,000. This is approximately the same as for the northwestern and northeastern regions of the United States mainland. For comparison, Miami, Florida, has 3,000 and Yuma, Arizona, has 4,000 hr of sunshine a year.

B. Soil Conditions

Specifically, the soil Great Group of Cryaquepts has developed on high mountains or at high latitudes, some with permafrost and some without.[2] Cryaquepts comprise 905,205 km^2 (349,500 $miles^2$) in the United States, about 9.9% of the total land area. The soil surface is characteristically organic, comprising about 30 cm (12 in.) of sphagnum moss, leaves, twigs, and roots. The roots of most plants are restricted to this organic layer. The mineral section of the soil is often silty with weak and platy structure, overlying rock fractured by frost action. On construction sites it is recommended to strip the organic soil surface and use it for topsoiling.

The interior area in Figure 67 has been divided into six soil and site groups for purposes of seeding and fertilizing recommendations. However, only Groups 4 and 5 are classified in the soil Great Group of Cryaquepts. These two groups will be used in this manual to illustrate the techniques of establishing vegetation (Figures 68 and 69). For the disturbed areas along the Alaskan pipeline, the soil exposed for seeding

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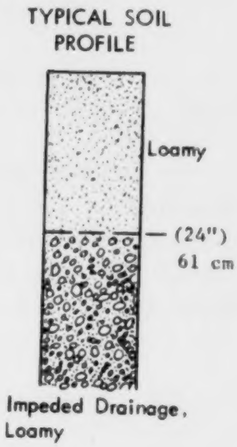
[1] U.S. Department of Commerce, "Climates of the States, Vol. II, Western States," National Oceanic and Atmospheric Administration, 975 pages (1974).

[2] Soil Survey Staff, "Soil Taxonomy," U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., October 1973.

The soils and sites in this group have textures ranging from silty clay loam to fine sandy loam. The natural drainage may be impeded by slowly permeable layers in the substrata, permafrost, or low lying positions on the landscape. The water table is usually more than 61 cm (2 ft) below the surface but may fluctuate to higher levels for short periods of time during the growing season.

If these soils and sites are drained, they are generally suitable for growing the same plants which are adapted to Group 1. If they are undrained, plant choices will be limited to those that are tolerant to cool, moist conditions.

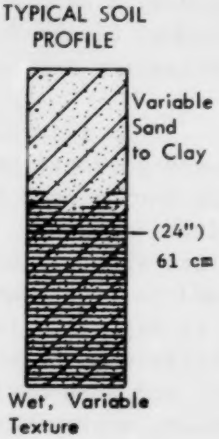


Major Soil Limitations	Drainage Class	Depth	USDA Texture	Engineering Classification Unified	Engineering Classification AASHO	Available Water Holding Capacity
Impeded drainage	Somewhat poorly drained or poorly drained	More than 51 cm (20 in.)	Silty clay loam, silt loam sandy loam, fine sandy loam	ML CL SM	A-2,A-4 A-6 Some A-7	More than 13 cm (5 in.) (may be water-logged for short periods)

Figure 68 - Soils With Moderate Limitations Due to Excess Moisture

This group of soils and sites has a wide range of textures and are generally wet throughout the growing season. The water table is usually within 61 cm (2 ft) of the surface. These wet conditions may be due to slowly permeable materials, high permafrost tables, slow surface runoff, or seepage from adjacent areas.

Many of these soils and sites are not feasible to drain, and plant choices are limited to those that are the most tolerant to cold, wet soil conditions. If they can be drained to maintain the water table to a depth of 61 cm (2 ft) or more, the choice of plants can be widened.



				Engineering Classification		Available Water Holding Capacity
Major Soil Limitations	Drainage Class	Depth	USDA Texture	Unified	AASHO	
Wetness (high water table)	Poorly drained	More than 51 cm (20 in.) May have up to 41 cm (16 in.) of peat on surface	Very wide range			Usually waterlogged

Figure 69 - Soils With Severe Limitations Due to Excess Moisture

or planting vegetation will vary more than will the surface of an undisturbed area; for this reason, on-site inspection will be necessary to modify the generalized recommendations. Contrasting soils should also be tested for more specific lime and fertilizer recommendations by sending a sample to the Extension Service, University of Alaska, Fairbanks, Alaska 99701. Before collecting the soil samples, write to the Extension Service for specific directions.

To illustrate the physical characteristics of permafrost, a soil-and-geologic profile to a depth of 13.7 m (45 ft) is presented from a deep boring near Fairbanks, Alaska, located in the central part of the interior area. The last glacier moved over most of this interior area was about 10,000 years ago. "Time zero" for soil formation can be assumed to have started at that time. Radiocarbon dating of the soil core in Figure 70 reveals that at a depth of 1.8 m (6 ft), the age of the organic material was 7,000 years; at 3.4 m (11 ft) it was 8,500 years; and at a depth of 10.4 m (34 ft) it was 30,700 years. By interpolation, approximately 1,000 years have been required to develop an average 0.3 m (1 ft) of soil.

C. The Problem

For approximately 3 years the construction of the Alaskan pipeline was delayed. Arguments against construction included:

1. The oil would be kept hot as it is pumped through the pipeline. The hot pipe, if buried in the soil, would melt the permafrost, collapse the soil-ice support, break the pipe, and spew millions of gallons of hot oil over the . . . "fragile tundra and beautiful forestland into its streams and rivers, melting the permafrost and triggering a whole series of disastrous effects, perhaps for hundreds of miles. Such a calamity might easily happen in a terrain forbidden to human technology because of its severe cold, treacherous instability, and its frequent earthquakes."

2. If the pipeline were supported above ground to better withstand possible earthquakes . . . "it would obstruct animal migrations, greatly deface the landscape, and still be subject to potential breakage."[1/]

[1/] Wilderness Society, "Alaska Alert-Russian Roulette in the Artic," 729 Fifteenth Street, N.W., Washington, D.C. 20005 (undated).

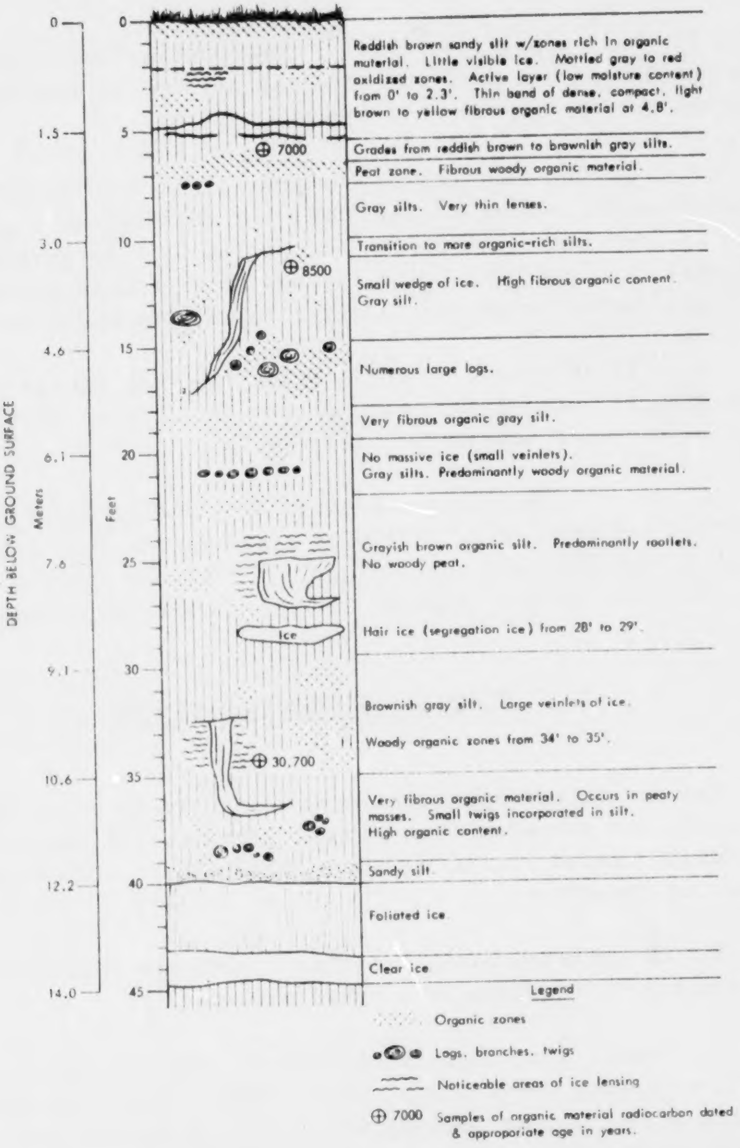

DEPTH BELOW GROUND SURFACE
Meters
Feet
0
1.5
3.0
4.6
6.1
7.6
9.1
10.6
12.2
14.0
0
5
10
15
20
25
30
35
40
45
Reddish brown sandy silt w/zones rich in organic material. Little visible ice. Mottled gray to red oxidized zones. Active layer (low moisture content) from 0' to 2.3'. Thin band of dense, compact, light brown to yellow fibrous organic material at 4.8'.
⊕ 7000
Grades from reddish brown to brownish gray silts.
Peat zone. Fibrous woody organic material.
Gray silts. Very thin lenses.
Transition to more organic-rich silts.
⊕ 8500
Small wedge of ice. High fibrous organic content. Gray silt.
Numerous large logs.
Very fibrous organic gray silt.
No massive ice (small veinlets).
Gray silts. Predominantly woody organic material.
Grayish brown organic silt. Predominantly rootlets.
No woody peat.
Ice
Hair ice (segregation ice) from 28' to 29'.
Brownish gray silt. Large veinlets of ice.
Woody organic zones from 34' to 35'.
⊕ 30,700
Very fibrous organic material. Occurs in peaty masses. Small twigs incorporated in silt.
High organic content.
Sandy silt
Foliated ice
Clear ice
Legend
Organic zones
Logs, branches, twigs
Noticeable areas of ice lensing
⊕ 7000 Samples of organic material radiocarbon dated & approporiate age in years.

Figure 70 - Typical Record of Ice in Permafrost (Sellman[a])

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[a] Sellman, P. V., "Geology of the USACRREL Permafrost Tunnel, Fairbanks, Alaska," USACRREL Technical Report 199 (1967).

The president of the Alaska Pipeline Service Company, responded with these statements:[1]

1. "All design, materials, and construction practices employed in the installation of the pipeline will be in accordance with safe practice for the Arctic environment. . ."

2. "Engineering and procurement plans were initiated under the Federal Mineral Leasing Act of 1920, but the National Environmental Policy Act of 1969 established new 'ground rules.' An environmental impact statement, in compliance with the new Act has been prepared and filed with the Secretary of the Interior in Washington, D.C."

3. "It is almost an engineering law that energy consumption correlates directly with gross national product. Gross national product has been accepted as a measure of progress."

4. ". . . we are currently in a period of hysteria in which people without information or skills or training can long delay developments vital to our national well being. . . This is far too important a matter to be left in the hands of untrained, irrational people."

II. TUNDRA--A UNIQUE ENVIRONMENT

The Arctic and Subarctic Regions of Alaska along the route of the pipeline are so unfamiliar to most planners and resource managers in mainland United States that a special effort will be made here to characterize the area:

1. Low precipitation but also a very low rate of evaporation; the net result of which is a humid climate.

2. Vegetation consists of lichens, mosses, sedges, willow trees, and low-growing paper birch trees. Other common hardwoods include quaking aspen, balsam poplar, and black cottonwood that commonly grow in mixtures and with white spruce and black spruce.[2]

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[1] Patton, E. L., "Transportation of Oil from the Arctic by the Trans Alaska Pipeline," Society of Petroleum Engineers of AIME, Paper No. SPE 3252, 8 pages (1971).

[2] U.S. Forest Service, "Silvicultural Systems for the Major Forest Types of the United States," Agricultural Handbook 445, U.S. Department of Agriculture, 114 pages (1973).

3. The principal animals are grizzly bear, moose, caribou, wolf, wolverine, fox, ground squirrel, lemming, and Arctic shrew. Birds include geese, ducks, shore birds, whistling swan, loon, gulls, terns, hawks, eagles, snowy owl, plover, and ptarmigan. (Vegetation established to stabilize the soil along the Alaskan pipeline may be eaten by some of the wild animals and birds.)

4. Soils in the Arctic and Subarctic Alaska, in nature, have from about 15 to 30 cm (6 to 12 in.) of organic matter on the surface. Even without much live vegetation to shade the surface, this organic blanket is effective in reducing the penetration of heat from the sun and thus to keep stable a soil that has ice lenses or permafrost at shallow depths. Under natural conditions, the soils are relatively stable.

Any construction activity that exposes bare mineral soil to the sun causes the ice in the soil to melt. Following the melting, slopes begin to fail causing excess flows of surface water to carry sediment toward water courses. In many situations, the surface water will melt a vertical ice lense and move down the cavity thus opened, causing rills, gullies, and an underground lake.1/ Topsoiling with the natural organic surface soil will insulate against melting of permafrost and subsequent soil collapse.

5. During freezing weather, all earthmoving, such as in cut and fill slopes and borrow areas, should be done around the clock. The reason is that any delays will permit the soil to freeze, and frozen soil cannot be packed with unfrozen soil to achieve uniform density and stability. Upon becoming heated by the sun, the frozen soil chunks will leave a pocket or a sunken surface above them.

III. PERMAFROST

A. Introduction

For many years, the term permafrost has been used as a shortened, coined word to mean "permanently frozen soil."

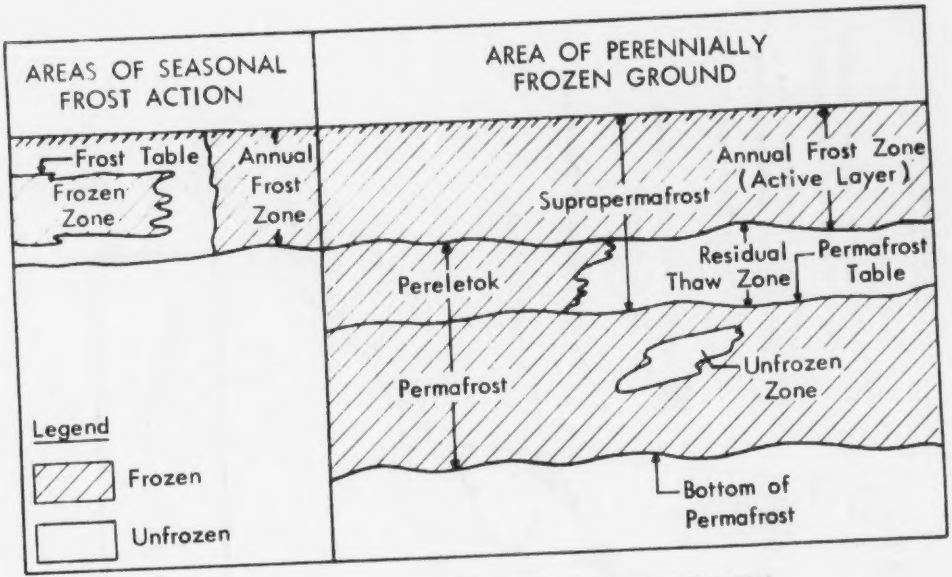
1/ Departments of the Army and the Air Force, "Arctic and Subarctic Construction: Foundations for Structures," Technical Manual No. 5-852-4, Chapter 4, Washington, D.C. (1972).

One succinct characterization of permafrost is that it is neither ice, nor water, nor soil, but all three with horizontal, vertical, and seasonal variability (Figure 71). This figure illustrates no permafrost--only an annual frost zone, as is common in the northern part of the mainland of the United States. On the right side of the drawing, the zone labeled "suprapermafrost" is the entire zone above the top of the permafrost. Within this zone are two subzones--the annual frost zone (as on the left side of the drawing), and the pereletok--a transition zone between the permafrost and the annual frost zone which may be either thawed or frozen for one or two summers.

In Alaska, the southern boundary of continuous permafrost is approximately along the Arctic Circle, and the southern boundary of discontinuous permafrost is along the northern side of Bristol Bay and the Gulf of Alaska at an elevation of about 152 m (500 ft). At all locations, permafrost is greater under dense forests, on mineral soils covered with a thick surface mat of organic matter, in fine-textured soils, and on tops of hills. It is estimated that approximately 10% of the land surface of Alaska is in peat or muck bogs or swamps (muskegs). Low-lying organic soils seldom have continuous permafrost, but in themselves they present very serious problems of construction because of their very low trafficability (Figures 72 and 73).

B. Soil Disturbance

Any wildfire or construction activity that destroys the protective organic surface layer will start the process of thawing of seasonally frozen ice or permafrost. The result is subsidence, surplus water that starts flowing, and a weakened soil structure that releases silt and clay that move by mass flow with melt-water and pollute water courses.


AREAS OF SEASONAL FROST ACTION
AREA OF PERENNIALLY FROZEN GROUND
Frost Table
Frozen Zone
Annual Frost Zone
Suprapermafrost
Annual Frost Zone (Active Layer)
Residual Thaw Zone
Permafrost Table
Pereletok
Permafrost
Unfrozen Zone
Bottom of Permafrost
Legend
Frozen
Unfrozen

DEFINITIONS OF SOIL AND OTHER TERMS RELATING TO FROZEN GROUND AREAS

Annual frost zone (active layer). The top layer of ground subject to annual freezing and thawing. In arctic and subarctic regions where annual freezing penetrates to the permafrost table, suprapermafrost and the annual frost zone are identical.

Excess ice. Ice in excess of the fraction which would be retained as water in the soil voids upon thawing.

Frost table. The surface, usually irregular, which represents the level, at any time in spring and summer, to which thawing of the seasonal frozen ground has penetrated

Frozen zone. A range of depth within which the soil is frozen. The frozen zone may be bounded both top and bottom by unfrozen soil, or at the top by the ground surface.

Ground ice. A body of more or less clear ice within frozen ground.

Ice wedge. A wedge shaped ice mass in permafrost, usually associated with fissure polygons

Icing. A surface ice mass formed by freezing of successive sheets of water.

Muskeg. Poorly drained organic terrain consisting of a mat of living vegetation overlying peat of varying thickness, from a few inches to many feet.

Permafrost. Perennially frozen ground.

Permafrost table. The surface which represents the upper limit of permafrost.

Pereletok. A frozen layer at the base of the active layer which remains unthawed for one or two summers.

Residual thaw zone. A layer of unfrozen ground between the permafrost and the annual frost zone. This layer does not exist where annual frost extends to permafrost.

Suprapermafrost. The entire layer of ground above the permafrost table.

Source: Department of the Army Technical Manual.
Department of the Air Force Manual
Departments of the Army and the Air Force, July 1966.

Figure 71 - Illustrations of Terminology Used to Identify Characteristic Structural Classifications of Soil Features in Areas of Frozen Ground

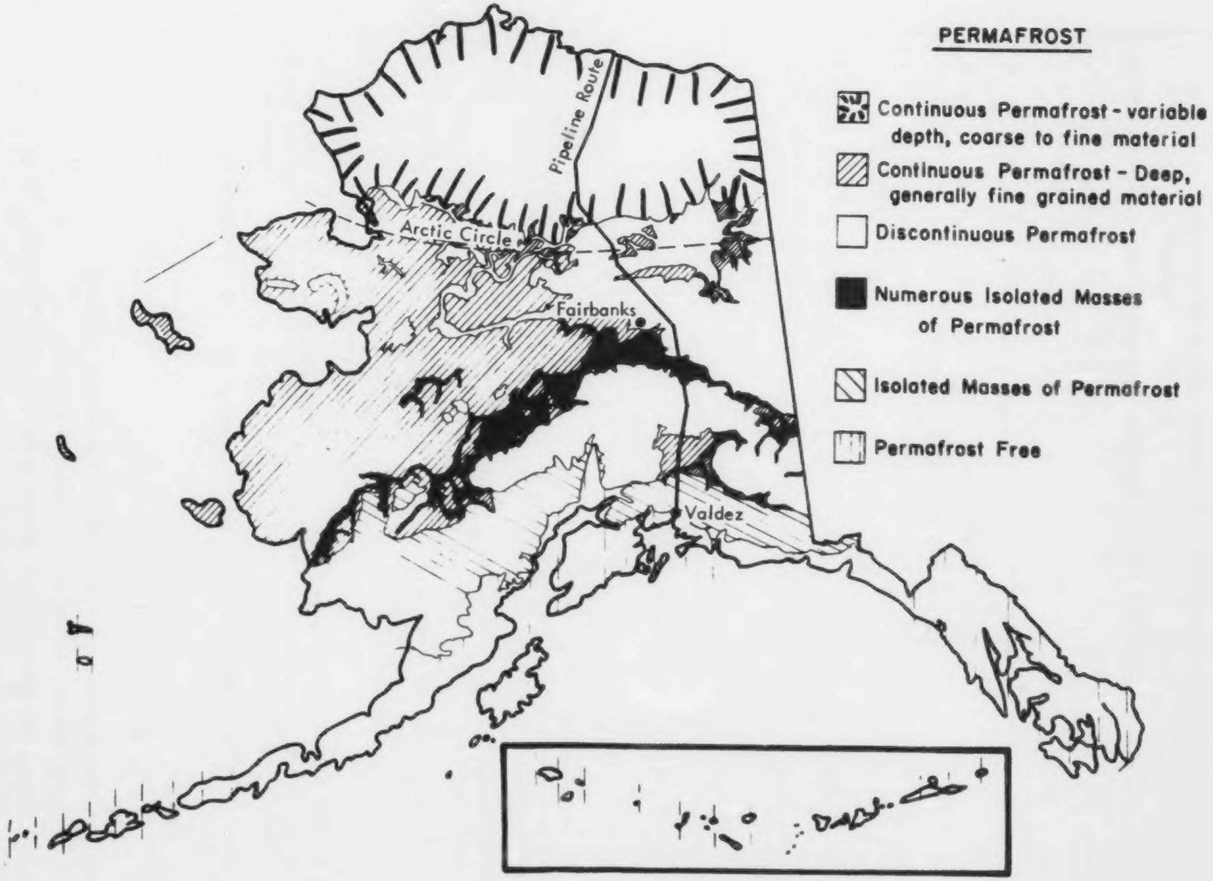

PERMAFROST
Continuous Permafrost - variable depth, coarse to fine material
Continuous Permafrost - Deep, generally fine grained material
Discontinuous Permafrost
Numerous Isolated Masses of Permafrost
Isolated Masses of Permafrost
Permafrost Free
Pipeline Route
Arctic Circle
Fairbanks
Valdez

Figure 72 - Location of the Relative Abundance of Permafrost in Alaska
(Courtesy of U.S. Bureau of Land Management)

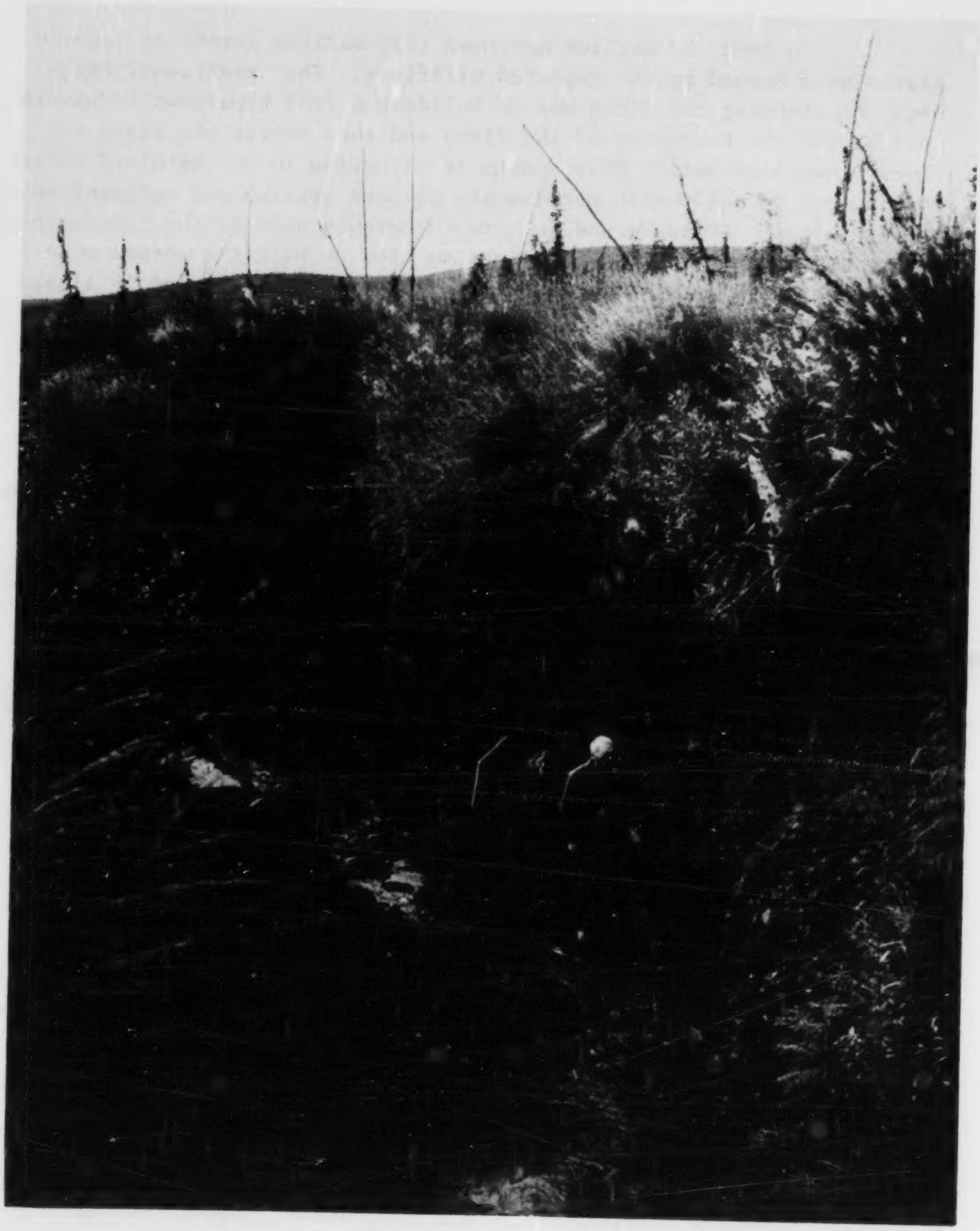


Figure 73 - Gully Erosion in Alaska Resulting from Surface Waters Running Down a Constructed Pipeline. Because of permafrost, water cannot percolate downward (see Figure 71). (Courtesy of U.S. Bureau of Land Management)

In 1972, 90 million hectares (222 million acres) of land in Alaska were burned by 641 reported wildfires. The traditional technique of stopping the fires was to bulldoze a fuel breakdown to mineral soil around the perimeter of the fires and then permit the fires to "burn themselves out." This system is effective in the mainland United States, but on soils with permafrost, serious erosion and sediment movement result.[1] Standard and routine techniques used in the conterminous 48 States of constructing fire lines to slow or halt the spread of a fire do not work in Alaska. When the same practice is tried in Alaska on fine-textured soils with permafrost, the surface of the permafrost melts; the underlying ice prevents percolation; and finally the ice may collapse, and cavernous erosion, as well as surface gullies, result. The resulting silts and clays released by surface erosion add sediments to nearby streams and lakes.[2]

Techniques used to successfully control erosion on bare soils with permafrost include the building of a terrace across the slope of the fire lanes at intervals of 27 to 46 m (30 to 50 yd) to divert surplus surface water into undisturbed soil and vegetation along the sides of the fire lane and seeding an adapted grass and legume mixture over the entire fire lane, after liming and fertilizing the soil according to the recommendations resulting from a chemical soil test. The most successful grass seeded so far has been Manchar smooth bromegrass (Figures 74, 75, and 76).

Another recommended technique[3] consists of bulldozing the protective organic layer back over the mineral soil of the fire lanes after the fires have been suppressed and before the bulldozers leave the area.

---

[1] Bureau of Land Management, "Influence of Man-Caused Surface Disturbance in Permafrost Areas of Alaska," Report of special committee assigned by State Director of Alaska, U.S. Department of the Interior, 21 pages (1973).

McVee, C. V., "Permafrost Considerations in Land Use Planning Management," State Director, Bureau of Land Management in Alaska, Mimeographed, 13 pages (1973).

[2] Bolstad, R., "Catline Rehabilitation and Restoration," In: "Fire in the Northern Environment--A Symposium," 13 and 14 April 1971, University of Alaska, College (Fairbanks), Alaska, pp. 107-116 (1971).

[3] Lotspeich, F. B., E. W. Mueller, and P. J. Frey, "Effects of Large Scale Forest Fires on Water Quality in Interior Alaska," U.S. Department of the Interior, 115 pages, February 1970.

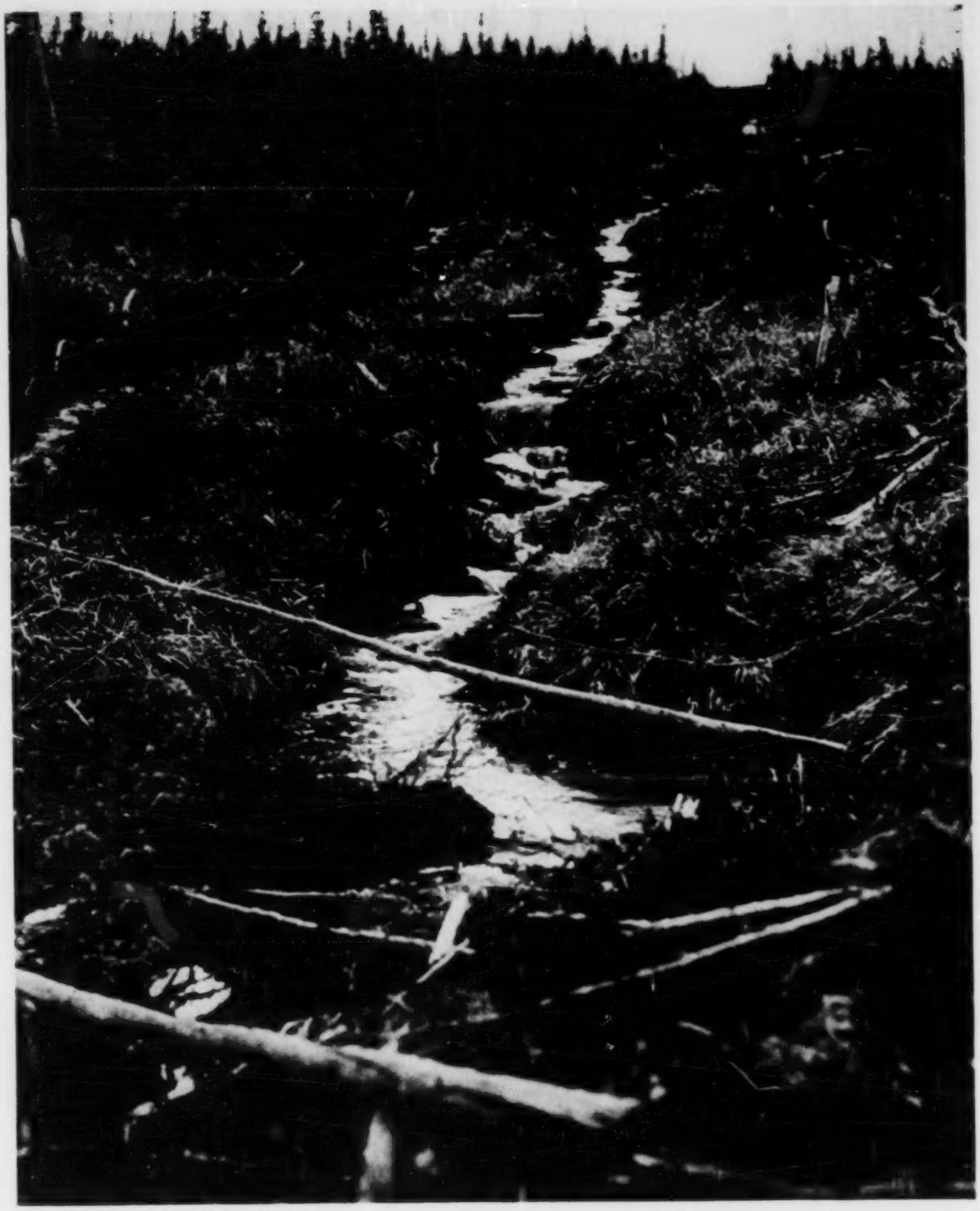


Figure 74 - A Roadway Through Ice-Rich Soil, Even on Gentle Slopes, Often Erodes Because the Surface Waters Cannot Move Downward (see Figure 75) (Courtesy of U.S. Bureau of Land Management)

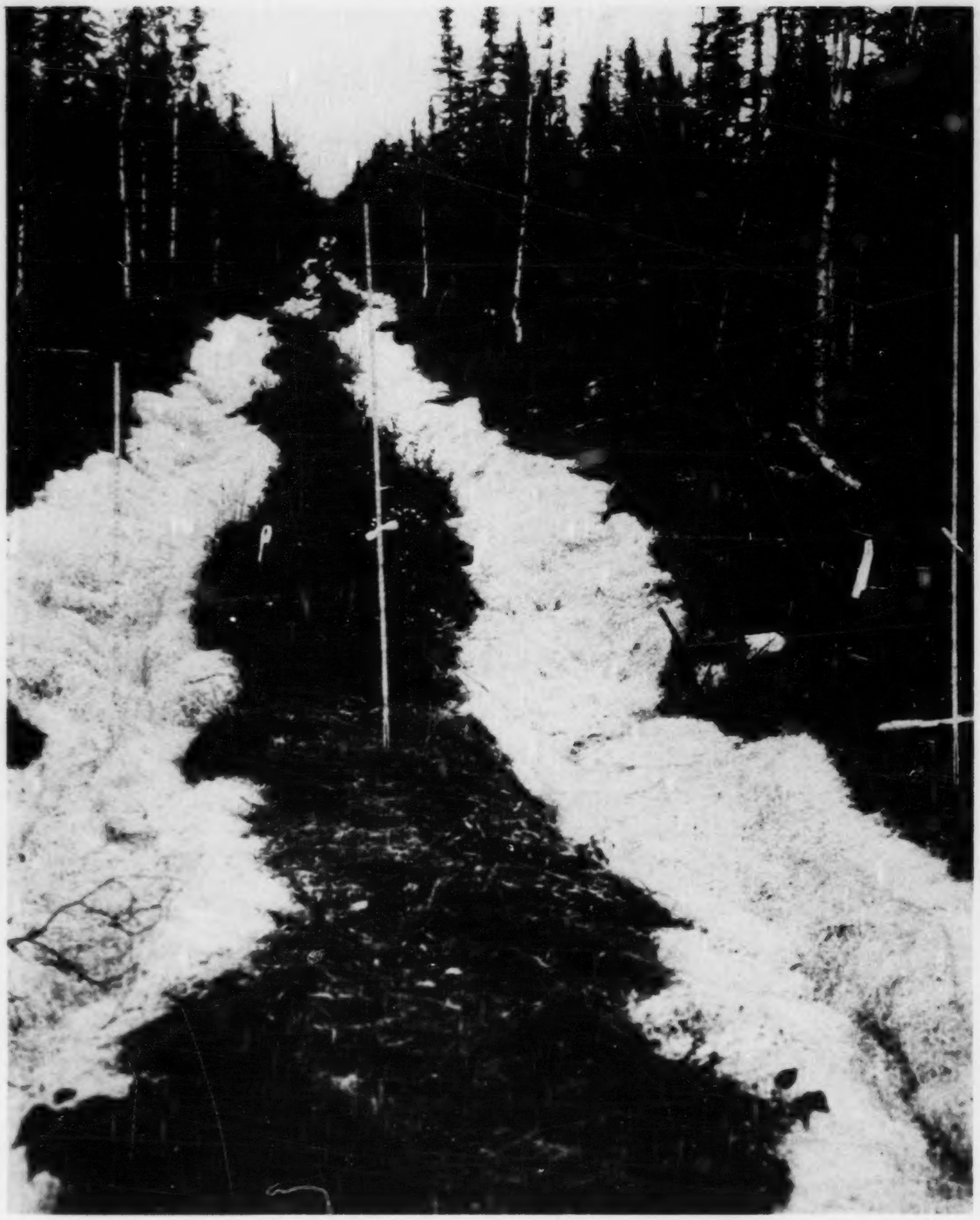


Figure 75 - The Same Roadway as in Figure 74 That has Been Seeded and Mulched With a Layer of Excelsior. Nearby evergreen branches would accomplish the same results (see Figure 76). (Courtesy of U.S. Bureau of Land Management)

Reproduced from best available copy.

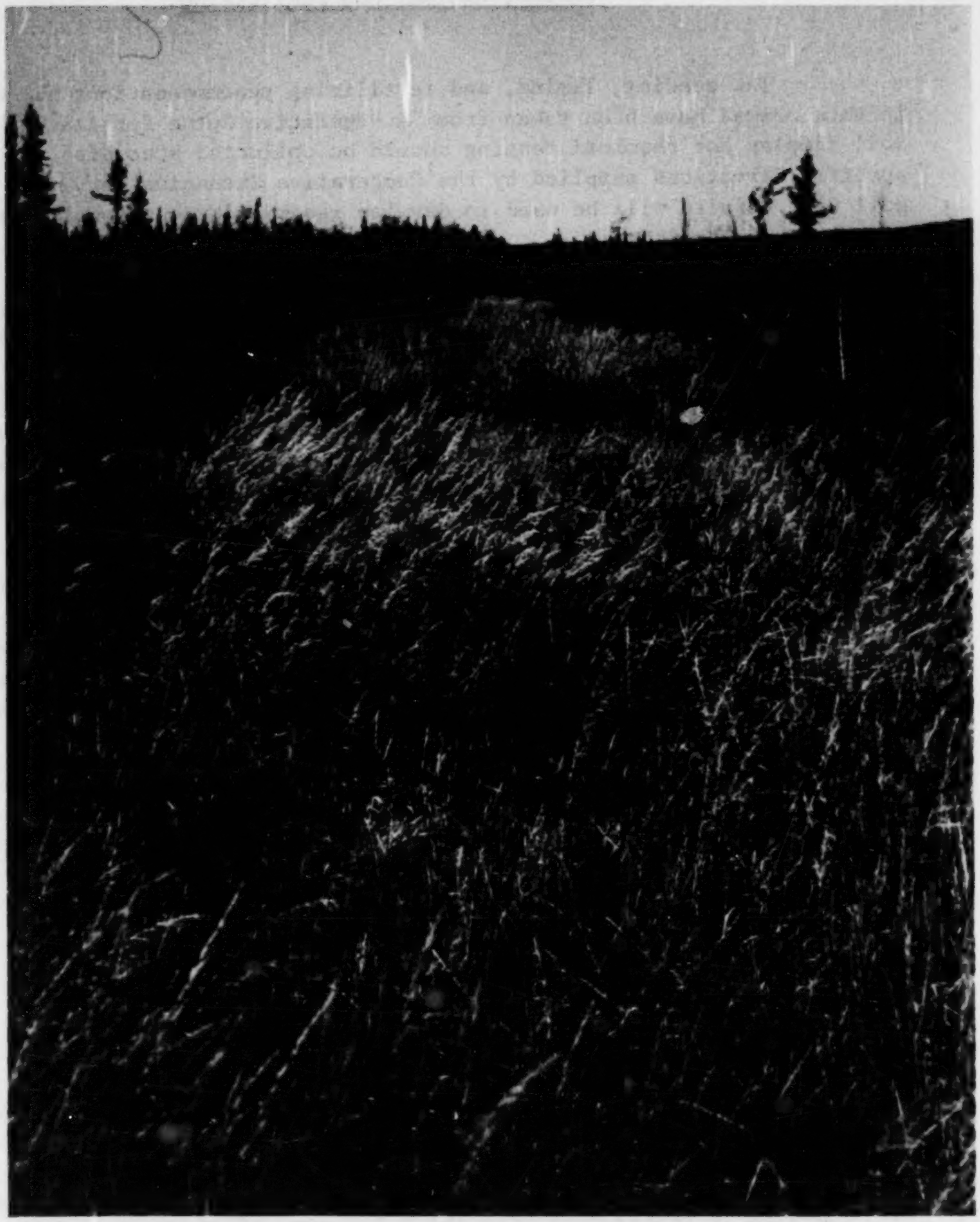


Figure 76 - The Same Road as in Figures 74 and 75, Showing an Excellent Stand of Adapted Grasses (Courtesy of U.S. Bureau of Land Management)

IV. SEEDING, LIMING, AND FERTILIZING

The seeding, liming, and fertilizing recommendations given in this manual have been taken from "A Vegetative Guide for Alaska."[1] Soil samples for chemical testing should be collected according to specific directions supplied by the Cooperative Extension Service. The soil test results will be used to develop recommendations for lime and fertilizer applications.

In the absence of a soil test, the "best estimate" is to add 27 g (60 lb) each of N, P_2O_5, and K_2O to each seeding for both the 1st and 2nd years.

Tables 22 and 23 show seeding mixtures for soil Groups 4 and 5, respectively. These mixtures are meant specifically for revegetating highly erosive or highly disturbed sites such as those in the interior area of Alaska along the Alaskan pipeline.

If recommended, lime should be applied and worked into the surface soil several months prior to time of seeding. All fertilizers should be applied and worked into the surface few inches of soil several months after applying lime and a few days prior to seeding. Lime and fertilizer should not be mixed and added together; neither should seed, lime, and fertilizer be applied at the same time.

V. ESTABLISHING VEGETATION ON THE SOIL GREAT GROUP OF CRYAQUEPTS

A. Site Preparation

Soils disturbed by construction activities, such as those along the Alaskan pipeline, usually provide a very poor seedbed for small-seeded plants. The soils are often stony, full of roots and stumps, and difficult to make into a uniform seedbed because of frozen

---

[1] "A Vegetative Guide for Alaska," prepared by the Soil Conservation Service in cooperation with the University of Alaska Institute of Agricultural Sciences, the Plant Science Research Division of the Agricultural Research Service, USDA, the University of Alaska Cooperative Extension Service, and the Alaska Association of Soil Conservation Subdistricts, Publication No. M7-N-22612, 50 pages (1972).

TABLE 22

SEEDING MIXTURES IN CENTRAL ALASKA FOR DISTURBED SOILS WITH MODERATE LIMITATIONS DUE TO EXCESS MOISTURE

Mixture No.	Mixtures and Species in Order of Preference	Variety Name in Order of Preference	Seeding Rate			
			Drilled		Broadcast	
			kg/ha	lb/acre	kg/ha	lb/acre
1	Creeping Foxtail	Garrison	11	10	22	20
	White Dutch or Alsike Clover		3	3	7	6
2	Creeping Foxtail	Garrison	11	10	22	20
	Kentucky Bluegrass	Nugget or	6	5	11	10
		Merion	6	5	11	10
	White Dutch or Alsike Clover		3	3	7	6
3	Timothy	Engmo	7	6	13	12
	Creeping Red Fescuegrass	Arctared or	9	8	18	16
		Olds	6	5	11	10
	White Dutch or Alsike Clover		3	3	7	6
4	Smooth Bromegrass	Manchar or	11	10	22	20
		Polar	17	15	34	30
	White Dutch or Alsike Clover		3	3	7	6

TABLE 23

SEEDING MIXTURES IN CENTRAL ALASKA FOR DISTURBED SOILS WITH SEVERE LIMITATIONS DUE TO EXCESS MOISTURE

Mixture No.	Mixtures and Species in Order of Preference	Variety Name in order of Preference	Seeding Rate			
			Drilled		Broadcast	
			kg/ha	lb/acre	kg/ha	lb/acre
1	Creeping Foxtail	Garrison	11	10	22	20
	Kentucky Bluegrass	Nugget or	6	5	11	10
		Merion	6	5	11	10
	White Dutch or Alsike Clover		3	3	7	6
2	Creeping Foxtail	Garrison	11	10	22	20
	White Dutch or Alsike Clover		3	3	7	6
3	Timothy	Engmo	7	6	13	12
	Kentucky Bluegrass	Nugget or	6	5	11	10
		Merion	6	5	11	10
	White Dutch or Alsike Clover		3	3	7	6

Note: The permafrost, a condition common to these soils, will normally change to surface seasonal frost if grass is grown for more than 5 years.

soil. In addition, standing water may hinder seedbed preparation in some soil areas, while other areas are at the proper moisture content. A good test for adequacy of seedbed preparation is to walk over the area; the heel impression should be barely visible when proper compaction and tilth have been achieved.

B. Seed Specifications

It is highly important to use seed of only northern varieties of grasses and legumes. If possible, buy only named certified seed from a reputable seed distributor. Many legume seeds must be scarified to increase germination percentage, and all legume seeds must be inoculated with the exact strain of bacteria recommended by specialists. Under adverse conditions, common on Cryaquepts, it is usually advisable to apply twice the recommended amount of bacterial inoculum to obtain satisfactory nodule bacteria.

C. Seeding Technology

The best time of year to sow seed is from May 15 to June 15, with August 10 as a "last chance" date to reduce the hazards of winter-killing of the seedlings. Annual ryegrass or grain rye can be seeded as late as September 1 if a quick-growing temporary fall and winter cover is needed to reduce erosion and sediment yield. If this "catch-crop" is sown, the recommended perennial mixture should be seeded the following spring.

Seed may be drilled, broadcast, or seeded with a hydroseeder. The preferred method is by drilling with a grass drill to a depth of 6 to 13 mm (1/4 to 1/2 in.). If broadcasting, use twice the amount of seed as for drilling. When the slopes are too steep for drilling, a hydroseeder can be used with success for seeding, fertilizing, and mulching.

D. Vegetative Plantings

Vegetative plantings include sprigging and sodding, and the planting of herbaceous and woody ground covers. Although more expensive, vegetative plantings are sometimes recommended for rapid establishment of protective covers on extremely sensitive sites such as on steep slopes.

Some grasses native to Alaska reproduce vigorously by rhizomes (underground stems), but produce very few seeds. Such grasses have a potential for propagation by sprigging.

Herbaceous and woody plants, both native and exotic, are available commercially in Alaska for planting on disturbed soils in the interior area. Although not much research work has been done on this subject, some successful plantings have been made. Tables 24 and 25 list plants most likely to grow successfully on Cryaquepts.

E. Maintenance

After seeding or planting, the plants must be kept moist, but not wet, until they have become well established. Watering must be done, therefore, at the time of the first indication of wilting of plants on the most droughty soils. Any areas with a poor stand may need reseeding, additional drainage, or mechanical structures for safe water disposal. A grass or straw mulch may be necessary if the slopes are very steep, or the soil is easily disturbed by the splash of raindrops. Woodchips or wood excelsior may also be used with success. Newer synthetic materials sometimes used as mulches are fiberglass and polyvinyl acetate.

VI. SOURCES OF ASSISTANCE

Sources of technical and on-site assistance in the Alaskan interior on vegetating soils in the interior of Alaska include:

Cooperative Extension Service, University of Alaska
Fairbanks, 99701, 1514 South Cushman, 907-479-7571
Homer, 99603, Box 195, 907-235-8698
Palmer, 99645, Box 736, 907-745-3360
Anchorage, 99504, 2651 Providence Avenue, 907-277-1488
Juneau, 99801, Box 109, 907-586-7131
Aniak, 99557

Institute of Agricultural Sciences, University of Alaska
Palmer Research Center
Palmer, Box AE, 907-479-7311

TABLE 24

HERBACEOUS GROUNDCOVERS FOR INTERIOR ALASKA

	Site Adaptation				Plant Characteristics					
					Height		Plant Spacing[a]			
Plant	Soil Texture	Drought Tolerance	Wet & Flood Tolerance	Acid Tolerance	cm	in.	cm	in.	Root System[b]	Cover Rate[c]
Yarrow	Coarse to Medium	Excellent	Poor	Good	46	18	8	3	Fib	Sl
Pink Milfoil	Coarse to Medium	Excellent	Poor	Good	15-5	6-2	8	3	Fib	Sl
Moss Sandwort	Coarse	Good	Excellent	Good	5	2	30	12	Fib	Rap
Dusty Miller	Coarse	Excellent	Poor	Fair	6	2-1/2	30	12	Rhiz	Rap
Snow-In-Summer	Medium	Good	Good	Good	8-15	3-6	90	36	Fib	Rap
Maiden Pink	Coarse	Good	Poor	Good	5-15	2-6	60	24	Rhiz	Med

---

[a] This is the approximate spacing in pure stands. Since most of these seeds are extremely small (10,000 to 225,000 seeds/oz) it is suggested that planting be done as a mixture with grass seed. The amount of seed to apply per acre would normally be approximately 1/2 cup.

[b] Type of root system: Fib-fibrous root system, Rhiz-rhizomatous.

[c] This is a relative spreading rate following establishment: Sl-slow, Rap-rapid, Med-medium.

TABLE 25

WOODY GROUNDCOVERS FOR INTERIOR ALASKA

	Site Adaptation				Plant Characteristics					
							Plant			
					Height		Spacing[a/]			
Plant	Soil Texture	Drought Tolerance	Wet & Flood Tolerance	Acid Tolerance	cm	in.	cm	in.	Root System[b/]	Cover Rate[c/]
Box Rosemary	Fine	Poor	Excellent	Excellent	30-60	12-24	1.8	6	Rhiz	Med
Dwarf Caragana	Medium	Excellent	Poor	Excellent	60-90	24-36	1.8	6	Fib	Med
Wintergreen	Fine	Poor	Excellent	Excellent	8	3	1.0	3	Fib (Stolons)	Med
Creeping Juniper	Coarse	Excellent	Poor	Good	30-46	12-18	2.4	8	Fib (Branch Tip)	Med
Cinquefoil	Medium	Excellent	Poor	Excellent	60-90	24-36	1.0	3	Fib	Sl
Indian Snowberry	Medium	Excellent	Poor	Good	60-90	24-36	1.8	6	Fib (Suckers)	Rap

---

[a/] This is an optimum spacing. Less dense plant spacing may require interplating with herbaceous groundcovers to achieve adequate ground coverage.

[b/] Type of root system: Fib-fibrous root system, Rhiz-rhizomatous.

[c/] This is a relative spreading rate following establishment: Sl-slow, Rap-rapid, Med-medium.

Soil Conservation Service, U.S. Department of Agriculture
Fairbanks, 1750 Westwood Way, 907-479-6767
Homer, Box 394, 907-235-8668
Palmer, Box F, 907-745-3350

ALASKA ASSOCIATION OF SOIL CONSERVATION SUBDISTRICTS

Alaska Association of Soil Conservation Subdistricts

President
Mile 41
Richardson Highway
Fairbanks 99701
Telephone: 907-488-2233

Vice President
Box 1279
Homer 99603
Telephone: 907-235-8542

Vice President
Box 742
Palmer 99645
Telephone: 907-745-4173

Secretary-Treasurer
Box AE
Palmer 99645
Telephone: 907-745-3257

Bureau of Land Management
U.S. Department of the Interior
555 Cordova Street
Anchorage, Alaska 99501

Department of Environmental Conservation
Juneau 99801
Telephone: 907-586-6721

Department of Highways
P.O. Box 1467
Juneau, Alaska 99801

Department of Natural Resources
Juneau 99801
Telephone: 907-586-6352

Federal Water Pollution Control Administration
Alaska Water Laboratory
U.S. Department of the Interior
College, Alaska 99701

U.S. Environmental Protection Agency
Alaska Water Laboratory
College (Br. Fairbanks) Alaska 99701
Telephone: 907-479-2251

VII. ADDITIONAL REFERENCES

"The Forest Ecosystem of Southeast Alaska 1. The Setting," General Technical Report PHW-12, Pacific Northwest Forest and Range Experiment Station, Portland Oregon; Forest Service, U.S. Department of Agriculture, 40 pages (1974).

Geological Survey, U.S. Department of the Interior, Washington, D.C. 20242.
Note: Topographic maps on a scale of 1:250,000 are available for most areas of Alaska. Write to the U.S. Geological Survey for a free list of available quandrangle maps.

"Influence of Man-Caused Surface Disturbance in Permafrost Areas of Alaska," Bureau of Land Management, U.S. Department of the Interior, 21 pages (1973).

Lotspeich, Frederick B., Ernst W. Mueller, and Paul J. Frey, "Effects of Large-Scale Forest Fires on Water Quality in Interior Alaska," Alaska Water Laboratory, Federal Water Pollution Control Administration, U.S. Department of the Interior, College, Alaska, 115 pages (1970).

"1973 Alaska Revegetation Workshop Notes," Cooperative Extension Service, University of Alaska, Fairbanks, No. RP-239, 68 pages (1973).

"A Vegetative Guide for Alaska," Cooperative Extension Service, University of Alaska, Fairbanks, No. M7-N-22612, 50 pages (1972).

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V. SUPPLEMENTARY INFORMATION

A. Location of State Extension Service Directors

State	Address	FTS	FTS Information and Assistance	Commercial Telephone No.
Alabama	Auburn University Auburn, Alabama 36830		205-263-7521	205-826-4444 or 821-1314
Alaska	University of Alaska Fairbanks, Alaska 99701		202-442-0150	907-479-7246
Arizona	University of Arizona Tucson, Arizona 85721		602-792-6011	602-884-2711
Arkansas	P.O. Box 391 Little Rock, Arkansas 72203		501-378-5011	501-376-6301
California	University of California 2200 University Avenue Berkeley, California 94720	415-486-3559	415-841-5121	415-642-7252
Colorado	Colorado State University Fort Collins, Colorado 80521	303-484-2273	303-837-0111	303-491-6281
Connecticut	University of Connecticut Storrs, Connecticut 06268		203-244-2000 203-244-2000	203-486-2917 203-486-4125
Delaware	University of Delaware Newark, Delaware 19711		302-654-6131	302-738-2504

State	Address	FTS	FTS Information and Assistance	Commercial Telephone No.
District of Columbia	Federal City College 1424 K Street, N.W. Washington, D.C. 20005		202-967-1221	202-727-2113
Florida	University of Florida Gainesville, Florida 32611		904-376-1681	904-392-1761
Georgia	University of Georgia Athens, Georgia 30601		404-546-2011	404-542-3824
Guam	University of Guam P.O. Box EK Agana, Guam 96910			
Hawaii	University of Hawaii Honolulu, Hawaii 96822			808-948-8234 808-948-8228
Idaho	University of Idaho Moscow, Idaho 83843		208-342-2711	208-885-6681
Illinois	University of Illinois Urbana, Illinois 61801		217-525-4011	217-333-2660
Indiana	Purdue University West Lafayette, Indiana 47907	317-633-7521 or 317-633-7675	317-633-7000	317-749-2413
Iowa	Iowa State University Ames, Iowa 50010	515-294-4576	515-232-0011	515-294-4576
Kansas	Kansas State University Manhattan, Kansas 66506		913-234-8661	913-532-5820

State	Address	FTS	FTS Information and Assistance	Commercial Telephone No.
Kentucky	University of Kentucky Lexington, Kentucky 40506	606-252-2775 606-252-2775	606-252-2312 606-252-2312	606-257-4772 606-257-2833
Louisiana	Louisiana State University Baton Rouge, Louisiana 70803	504-388-2386	504-348-0181	504-343-7444
Maine	University of Maine Orono, Maine 04473		207-942-8271	207-581-7200
Maryland	University of Maryland College Park, Maryland 20742		301-752-8460	301-454-3742
Massachusetts	University of Massachusetts Amherst, Massachusetts 01002		617-223-2100 617-223-2100	413-545-2766 413-545-2715
Michigan	Michigan State University East Lansing, Michigan 48823	517-337-4283	517-372-1910	517-355-2308
Minnesota	University of Minnesota St. Paul, Minnesota 55101		612-334-3012	612-373-1223
Mississippi	Mississippi State University Mississippi State, Mississippi 39762		601-948-7821	601-325-4436
Missouri	University of Missouri 309 University Hall Columbia, Missouri 65201		314-442-2271	314-882-4561 or 882-4662

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Montana	Montana State University Bozeman, Montana 59715		406-587-4511	406-994-3402
Nebraska	University of Nebraska Lincoln, Nebraska 68503	402-475-3621	402-475-2611	402-472-7211
Nevada	University of Nevada Reno, Nevada 89507		702-784-5911 702-784-5911	702-784-6611 702-784-6611
New Hampshire	University of New Hampshire Taylor Hall Durham, New Hampshire 03824	603-868-7732	603-669-7011	603-862-1520
New Jersey	Rutgers - the State University P.O. Box 231 New Brunswick, New Jersey 08903		201-846-4500	201-932-9306
New Mexico	New Mexico State University Las Cruces, New Mexico 88001		505-843-0311 505-843-0311	505-646-1806 505-646-3015
New York	New York State College of Agriculture Ithaca, New York 14850		607-772-1050	607-256-2117
North Carolina	North Carolina State University Raleigh, North Carolina 27607		919-755-4020	919-737-2811 or 737-2812
North Dakota	North Dakota State University Fargo, North Dakota 58102	701-237-5618	701-237-5771	701-237-8931

State	Address	FTS	FTS Information and Assistance	Commercial Telephone No.
Ohio	Ohio State University 2120 Fyffe Road Columbus, Ohio 43210	614-293-6181	614-469-6600 614-469-6600	614-422-6891 614-422-6181
Oklahoma	Oklahoma State University Stillwater, Oklahoma 74074	405-231-4322	405-253-4011	405-372-6211
Oregon	Oregon State University Corvallis, Oregon 97331	503-752-4203	503-752-4281	503-754-2713
Pennsylvania	The Pennsylvania State University University Park, Pennsylvania 16802		412-644-3311	814-863-0331
Puerto Rico	University of Puerto Rico Rio Piedras, Puerto Rico 00928			809-765-8000 or 764-0655
Rhode Island	University of Rhode Island Kingston, Rhode Island 02881		401-528-1000 401-528-1000	401-792-2476 401-792-2476
South Carolina	Clemson University Clemson, South Carolina 29631		803-765-5011	803-656-3382
South Dakota	South Dakota State University Brookings, South Dakota 57006		605-225-0250	605-688-4147
Tennessee	University of Tennessee P.O. Box 1071 Knoxville, Tennessee 37901	615-524-4257	615-524-4011	615-974-7114
Texas	Texas A&M University College Station, Texas 77843		713-846-8821	713-845-6411

State	Address	FTS	FTS Information and Assistance	Commercial Telephone No.
Utah	Utah State University Logan, Utah 84321		801-524-5500	801-752-4100
Vermont	University of Vermont Burlington, Vermont 05401		802-862-6501	802-656-2990
Virginia	Virginia Polytechnic Institute and State University Blacksburg, Virginia 24061		804-782-2000	703-951-6705
Virgin Islands	P.O. Box 166, Kingshill St. Croix, Virgin Islands 00850			809-773-0246
Washington	Washington State University Pullman, Washington 99163		509-838-4611	509-335-2511
West Virginia	West Virginia University 294 Coliseum Morgantown, West Virginia 26505		304-296-3441	304-293-5691
Wisconsin	University of Wisconsin 432 North Lake Street Madison, Wisconsin 53706		608-256-4441	608-262-9510
Wyoming	University of Wyoming Box 3354 University Station Laramie, Wyoming 82070		307-778-2220 307-778-2220	307-766-4133 307-766-3253

B. State Agricultural Experiment Station Directors

State	Address	Commercial Telephone No.
Alabama	Auburn, Alabama 36830	205-826-4840
Alaska	Institute of Agricultural Sciences University of Alaska Fairbanks, Alaska 99701	907-479-7188
Arizona	Tucson, Arizona 85721	602-884-2711
Arkansas	Fayetteville, Arkansas 72701	501-575-2253
California	University of California Berkeley, California 94720	415-642-3235
	College of Agricultural and Environmental Sciences University of California Davis, California 95617	916-752-0107
	Citrus Research Center Agricultural Experiment Station Riverside, California 92502	714-787-3101
	San Joaquin Valley Agricultural Research and Extension Center Parlier, California	209-646-2794
Colorado	Fort Collins, Colorado 80521	303-491-5371
Connecticut	New Haven, Connecticut 06504	203-787-7421
	Storrs, Connecticut 06268	203-486-2917
Delaware	Newark, Delaware 19711	302-738-2501
Florida	University of Florida Institute of Food and Agricultural Sciences Gainesville, Florida 32601	904-392-1784
Georgia	Athens, Georgia 30601	404-542-2376
	Experiment, Georgia 30212	404-227-9471

State	Address	Commercial Telephone No.
	Tifton, Georgia 31794	912-382-5561
Guam	Agana, Guam 96910	
Hawaii	University of Hawaii Honolulu, Hawaii 96822	808-948-8234
Idaho	Moscow, Idaho 83843	208-885-6151
Illinois	Urbana, Illinois 61801	217-333-0240
Indiana	West Lafayette, Indiana 47907	317-749-2461
Iowa	Agriculture and Home Economics Experiment Station Iowa State University Ames, Iowa 50010	515-294-2518
Kansas	Manhattan, Kansas 66502	913-532-6147
Kentucky	Lexington, Kentucky 40506	606-257-4772
Louisiana	Baton Rouge, Louisiana 70803	504-388-4181
Maine	Life Sciences and Agricultural Experiment Station University of Maine Orono, Maine 04473	207-581-7161
Maryland	College Park, Maryland 20742	301-454-3707
Massachusetts	Amherst, Massachusetts 01002	413-545-2766
Michigan	East Lansing, Michigan 48824	517-355-0123
Minnesota	St. Paul, Minnesota 55101	612-373-0751
Mississippi	Mississippi State Agricultural and Forestry Experiment Station Mississippi State, Mississippi 39762	601-325-5455

State	Address	Commercial Telephone No.
Missouri	Columbia, Missouri 65201	314-882-3846
Montana	Bozeman, Montana 59715	406-587-3121
Nebraska	Lincoln, Nebraska 68503	402-472-2045
Nevada	Reno, Nevada 89507	702-784-6611
New Hampshire	Durham, New Hampshire 03824	603-862-1450
New Jersey	New Brunswick, New Jersey 08903	201-247-1766
New Mexico	Las Cruces, New Mexico 88001	505-646-1806
New York	Ithaca, New York 14850	607-256-5420
	Geneva, New York 14456	315-787-2211
North Carolina	Raleigh, North Carolina 27607	919-737-2717
North Dakota	Fargo, North Dakota 58102	701-237-7654
Ohio	Agricultural Research and Development Center Ohio State University Columbus, Ohio 43210	614-422-6891
	Agricultural Research and Development Center Wooster, Ohio 44691	216-264-1021
Oklahoma	Stillwater, Oklahoma 74074	405-372-6211
Oregon	Corvallis, Oregon 97331	503-754-1251
Pennsylvania	University Park, Pennsylvania 16802	814-865-2541
Puerto Rico	Rio Piedras, Puerto Rico 00928	809-767-9705

State	Address	Commercial Telephone No.
Rhode Island	Kingston, Rhode Island 02881	401-792-2474
South Carolina	Clemson, South Carolina 29631	803-656-3141
South Dakota	Brookings, South Dakota 57006	605-688-5131
Tennessee	Knoxville, Tennessee 37901	615-974-7121
Texas	College Station, Texas 77843	713-845-3711
Utah	Logan, Utah 84321	801-752-4100
Vermont	Burlington, Vermont 05401	802-656-2980
Virginia	Agricultural and Life Sciences Research Division Virginia Polytechnic Institute and State University Blacksburg, Virginia 24061	703-951-5282
Virgin Islands	Kingshill, St. Croix, Virgin Islands 00850	
Washington	Pullman, Washington 99163	509-335-4563
West Virginia	Morgantown, West Virginia 26506	304-293-2395
Wisconsin	Madison, Wisconsin 53706	608-262-1251
Wyoming	Laramie, Wyoming 82070	307-766-4133

C. State Conservationists Offices of the U.S. Soil Conservation Service*

State	Address	FTS	Commercial Telephone No.
Alabama	Wright Building 138 South Gay Street P.O. Box 311 Auburn, Alabama 36830	205-887-4542	205-887-8070
Alaska	204 East 5th Avenue Room 217 Anchorage, Alaska 99501	907-274-7626	907-274-7626
Arizona	230 North 1st Avenue 6029 Federal Building Phoenix, Arizona 85025	602-261-3271	602-261-3271
Arkansas	Federal Building, Room 5029 700 West Capitol Street P.O. Box 2323 Little Rock, Arkansas 72203	501-378-5445	501-378-5445
California	2828 Chiles Road P.O. Box 1019 Davis, California 95616	916-678-4411	
Colorado	2490 West 26th Avenue Room 313 P.O. Box 17107 Denver, Colorado 80217	303-837-4275	303-837-4275
Connecticut	Mansfield Professional Park Route 44A Storrs, Connecticut 06268	203-244-2547	203-429-9361
Delaware	Treadway Towers, Suite 2-4 Nine East Loockerman Street Dover, Delaware 19901	302-658-6448	302-678-0750
Florida	Federal Building P.O. Box 1208 Gainesville, Florida 32601	904-377-3277	904-373-2493

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* As of August 1974.

State	Address	FTS	Commercial Telephone No.
Georgia	Heritage Building 468 North Milledge Avenue P.O. Box 832 Athens, Georgia 30601	404-546-2275	404-546-2275
Hawaii	440 Alexander Young Building Honolulu, Hawaii 96813	808-546-3165	808-546-3165
Idaho	Room 345 304 North 8th Street Boise, Idaho 83702	208-342-2601	208-342-2711
Illinois	Federal Building 200 West Church Street P.O. Box 678 Champaign, Illinois 61820	217-356-1147	217-356-3785
Indiana	Atkinson Square-West Suite 2200 5610 Crawfordsville Road Indianapolis, Indiana 46224	317-633-7201	317-633-7201
Iowa	823 Federal Building 210 Walnut Street Des Moines, Iowa 50309	515-284-4260	515-284-4260
Kansas	760 South Broadway P.O. Box 600 Salina, Kansas 67401	913-827-9728	913-823-9535
Kentucky	333 Waller Avenue Lexington, Kentucky 40504	606-252-2749	606-252-2312
Louisiana	3737 Government Street P.O. Box 1630 Alexandria, Louisiana 71301	318-445-6611	318-448-3421
Maine	USDA Building University of Maine Orono, Maine 04473	207-942-8393	207-866-2132

State	Address	FTS	Commercial Telephone No.
Maryland	Room 522, Hartwick Building 4321 Hartwick Road College Park, Maryland 20740	301-344-4180	301-344-4180
Massachusetts	27-29 Cottage Street Amherst, Massachusetts 01002	413-549-0650	413-549-0650
Michigan	1405 Harrison Road East Lansing, Michigan 48823	517-337-4242	517-372-1910
Minnesota	200 Federal Building and U.S. Courthouse 316 North Robert Street St. Paul, Minnesota 55101	612-725-7675	612-725-7675
Mississippi	Milner Building, Room 490 P.O. Box 610 Jackson, Mississippi 39205	601-948-2405	601-948-7821
Missouri	Parkade Plaza Shopping Center (Terrace Level) P.O. Box 459 Columbia, Missouri 65201	314-442-3141	314-442-2271
Montana	Federal Building P.O. Box 970 Bozeman, Montana 59715	406-587-3322	406-587-4511
Nebraska	134 South 12th Street Lincoln, Nebraska 68508	402-475-3301	402-475-3301
Nevada	U.S. Post Office Building P.O. Box 4850 Reno, Nevada 89505	702-784-5304	702-784-5304
New Hampshire	Federal Building Durham, New Hampshire 03824	603-868-7734	603-868-7582
New Jersey	1370 Hamilton Street P.O. Box 219 Somerset, New Jersey 08873	201-846-4720	201-846-4500
New Mexico	517 Gold Avenue, S.W. P.O. Box 2007 Albuquerque, New Mexico 87103	505-766-2173	505-766-2173

State	Address	FTS	Commercial Telephone No.
New York	Midtown Plaza, Room 400 700 East Water Street Syracuse, New York 13210	315-473-3530	315-473-3530
North Carolina	Federal Office Building 310 New Bern Avenue Fifth Floor, P.O. Box 27307 Raleigh, North Carolina 27611	919-755-4210	919-755-4210
North Dakota	Federal Building P.O. Box 1458 Bismarck, North Dakota 58501	701-255-4421	701-255-4011
Ohio	311 Old Federal Building Third and State Streets Columbus, Ohio 43215	614-469-6785	614-469-6785
Oklahoma	Agriculture Building Farm Road and Brumley Street Stillwater, Oklahoma 74074	405-253-4204	405-253-4204
Oregon	Washington Building 1218 Southwest Washington Street Portland, Oregon 97205	503-221-2751	503-221-2751
Pennsylvania	Federal Building and Courthouse Box 985 Federal Square Station Harrisburg, Pennsylvania 17108	717-782-2297	717-782-2297
Puerto Rico	Caribbean Area 1409 Ponce de Leon Avenue Stop 20 Santurce, Puerto Rico 00908		809-725-8966
Rhode Island	222 Quaker Lane West Warwick, Rhode Island 02893		401-828-1300
South Carolina	Federal Building 901 Sumter Street Columbia, South Carolina 29201	803-765-5681	803-765-5681

State	Address	FTS	Commercial Telephone No.
South Dakota	239 Wisconsin Avenue, S.W. P.O. Box 1357 Huron, South Dakota 57350	605-352-8333	605-352-8651
Tennessee	561 U.S. Courthouse Nashville, Tennessee 37203	615-749-5471	615-749-5471
Texas	16-20 South Main Street P.O. Box 648 Temple, Texas 76501	817-773-1214	817-773-1711
Utah	4012 Federal Building 125 South State Street Salt Lake City, Utah 84111	801-524-5052	801-524-5052
Vermont	96 College Street Burlington, Vermont 05401	802-862-6261	802-862-6501
Virginia	Federal Building, Room 7408 400 North 8th Street P.O. Box 10026 Richmond, Virginia 23240	804-782-2457	804-782-2457
Washington	360 U.S. Courthouse West 920 Riverside Avenue Spokane, Washington 99201	509-456-3711	509-456-3711
West Virginia	75 High Street P.O. Box 865 Morgantown, West Virginia 26505	304-296-3151	304-599-7151
Wisconsin	4601 Hammersley Road P.O. Box 4248 Madison, Wisconsin 53711	608-252-5351	608-256-4441
Wyoming	Federal Office Building P.O. Box 2440 Casper, Wyoming 82601	307-265-3201	307-265-5550

D. State Highway Department Locations

State	Address
Alabama	State Highway Department State Highway Building Montgomery, Alabama 36104
Alaska	Department of Highways P.O. Box 1467 Juneau, Alaska 99801
Arizona	Arizona Highway Department 206 South 17th Avenue Phoenix, Arizona 85007
Arkansas	Arkansas State Highway Department P.O. Box 2261 9500 New Benton Highway Little Rock, Arkansas 72203
California	California Department of Transportation Division of Highways 1120 North Street P.O. Box 1499 Sacramento, California 95807
Colorado	Department of Highways 4201 East Arkansas Avenue Denver, Colorado 80222
Connecticut	Connecticut State Department of Transportation 24 Wolcott Hill Road Wethersfield, Connecticut 06109
Delaware	Department of Highways and Transportation Transportation and Public Safety Administration Building P.O. Box 151 Dover, Delaware 19901
District of Columbia	Department of Highways and Transportation Presidential Building, Room 519 415 12th Street, N.W. Washington, D.C. 20004

State	Address
Florida	Florida Department of Transportation Haydon Burns Building Tallahassee, Florida 32304
Georgia	Division of Planning and Progress Georgia Department of Transportation No. 2 Capitol Square Atlanta, Georgia 30334
Hawaii	Hawaii Highways Division Department of Transportation 869 Punchbowl Street Honolulu, Hawaii 96813
Idaho	Department of Highways 3211 West State Street P.O. Box 7129 Boise, Idaho 83707
Illinois	Department of Transportation Administration Building 2300 South 31st Street Springfield, Illinois 62764
Indiana	Indiana State Highway Commission State Office Building 100 North Senate Avenue Indianapolis, Indiana 46204
Iowa	Iowa State Highway Commission Highway Commission Building 826 Lincoln Way Ames, Iowa 50010
Kansas	State Highway Commission of Kansas State Office Building Topeka, Kansas 66612
Kentucky	Division of Planning Bureau of Highways Kentucky Department of Transportation State Office Building Ann Street Frankfort, Kentucky 40601

State	Address
Louisiana	Louisiana Department of Highways Capitol Station P.O. Box 4245 Baton Rouge, Louisiana 04330
Maryland	Maryland State Highway Administration 300 West Preston Street P.O. Box 717 Baltimore, Maryland 21201
Massachusetts	Bureau of Transportation Planning and Development Massachusetts State Department of Public Works 100 Nashua Street Morton Building, 5th Floor Boston, Massachusetts 02114
Michigan	Michigan Department of State Highways State Highway Building 425 West Ottawa Lansing, Michigan 48904
Minnesota	Department of Highways State Highway Building St. Paul, Minnesota 55101
Mississippi	Mississippi State Highway Department Highway Laboratory Building 412 Woodrow Wilson Avenue P.O. Box 1850 Jackson, Mississippi 39205
Missouri	Missouri State Highway Commission State Highway Building 119 West Capitol Jefferson City, Missouri 65102
Montana	Department of Highways East 6th Avenue and Roberts Street Helena, Montana 59601
Nebraska	Department of Roads South Junction of U.S. 77 and N-2 Lincoln, Nebraska 68509

State	Address
Nevada	Nevada Department of Highways State Highway Building 1263 South Stewart Street Carson City, Nevada 89701
New Hampshire	New Hampshire Department of Public Works and Highways John O. Morton Building Concord, New Hampshire 03301
New Jersey	New Jersey State Department of Transportation 1035 Parkway Avenue Trenton, New Jersey 08625
New Mexico	New Mexico State Highway Department P.O. Box 1149 Santa Fe, New Mexico 87501
New York	New York State Department of Transportation 1220 Washington Avenue Albany, New York 12226
North Carolina	Division of Highways North Carolina Department of Transportation and Highway Safety State Highway Building Raleigh, North Carolina 27602
North Dakota	State Highway Department State Highway Building Bismarck, North Dakota 58501
Ohio	Ohio Department of Transportation Department of Transportation Building 25 South Front Street Columbus, Ohio 43215
Oklahoma	Oklahoma Department of Highways Jim Thorpe Building Lincoln Boulevard at NE 21st Street Oklahoma City, Oklahoma 73105
Oregon	State Department of Transportation Oregon Highway Division State Highway Building Salem, Oregon 97310

State	Address
Pennsylvania	Pennsylvania Department of Transportation 1118 State Street P.O. Box 2926 Harrisburg, Pennsylvania 17120
Puerto Rico	Puerto Rico Highway Authority P.O. Box 3909, G.P.O. San Juan, Puerto Rico 00936
Rhode Island	Department of Transportation State Office Building, Smith Street Providence, Rhode Island 02903
South Carolina	State Highway Department 1100 Senate Street Columbia, South Carolina 29202
South Dakota	Department of Transportation Pierre, South Dakota 57501
Tennessee	Department of Transportation Transportation Building Nashville, Tennessee 37219
Texas	Texas Highway Department P.O. Box 5051 Austin, Texas 78703
Utah	Utah State Department of Highways 757 West 2nd South Salt Lake City, Utah 84104
Vermont	State of Vermont Department of Highways State Administration Building Montpelier, Vermont 05602
Virginia	Department of Highways 1221 East Broad Street Richmond, Virginia 23219
Washington	Department of Highways Highway Administration Building Maple Park at Franklin Olympia, Washington 98501

State	Address
West Virginia	West Virginia Department of Highways 1900 Washington Street, East Charleston, West Virginia 25305
Wisconsin	Department of Transportation Hill Farm 4802 Sheboygan Avenue Madison, Wisconsin 53702
Wyoming	Wyoming Highway Department Cheyenne, Wyoming 82001

E. State Departments of Agriculture

State		Address	Commercial Telephone No.
Alabama	Commissioner	Department of Agriculture and Industries, State Office Building, 501 Dexter Avenue, P.O. Box 220, Montgomery, Alabama 36104	205-269-6141 and 205-264-4290
Alaska	Director	Department of Agriculture, P.O. Box 800 Palmer, Alaska 99645	907-745-3236
American Samoa	Director	Department of Agriculture, Pago Pago, American Samoa 96920	
Arizona	Director	Arizona Commission of Agriculture and Horticulture, P.O. Box 6189, Phoenix, Arizona 85005	602-271-4191
Arkansas	Director	Arkansas State Plant Board, P.O. Box 1069, Little Rock, Arkansas 72203	501-371-1021
California	Director	Department of Agriculture, 1220 N Street, Agriculture Building, Sacramento, California 95814	916-445-7126
Colorado	Commissioner	Department of Agriculture, 424 State Services Building, 1525 Sherman Street, Denver, Colorado 80203	303-892-2811
Connecticut	Commissioner	Department of Agriculture and Natural Resources, State Office Building, Hartford, Connecticut 06115	203-566-4667

State		Address	Commercial Telephone No.
Delaware	Secretary	Department of Agriculture, Drawer D, Dover, Delaware 19901	302-678-4811
Florida	Commissioner	Department of Agriculture and Consumer Services, The Capitol, Tallahassee, Florida 32304	904-599-7345
Georgia	Commissioner	Department of Agriculture, Agriculture Building, Capitol Square, Atlanta, Georgia 30334	404-656-3600
Guam	Director	Guam Department of Agriculture, Government of Guam, USA, Agana, Guam 96910	
Hawaii	Chairman	Department of Agriculture, P.O. Box 5425, Honolulu, Hawaii 96814	808-841-3071
Idaho	Commissioner	Idaho Department of Agriculture, P.O. Box 790, Boise, Idaho 83701	208-384-3242
Illinois	Director	Department of Agriculture, State Fairground, Springfield, Illinois 62706	217-525-2274
Indiana	Director	Agricultural Experiment Station, 102 AES Building, Purdue University, West Lafayette, Indiana 47907	317-749-2461
Iowa	Secretary	Department of Agriculture, State House, Des Moines, Iowa 50319	515-281-5321
Kansas	Secretary	State Board of Agriculture, 1025-S State Office Building, Topeka, Kansas 66612	913-296-3556

State		Address	Commercial Telephone No.
Kentucky	Commissioner	Department of Agriculture, Capitol Annex, Frankfort, Kentucky 40601	502-564-4696
Louisiana	Commissioner	Department of Agriculture and Immigration, P.O. Box 44302, Capitol Station, Baton Rouge, Louisiana 70804	504-389-5453
Maine	Commissioner	Department of Agriculture, State Office Building, Augusta, Maine 04330	207-289-3871
Maryland	Director	State Board of Agriculture Programs, State Board of Agriculture, College Park, Maryland 20742	301-454-3713
Massachusetts	Commissioner	Department of Agriculture, State Office Building, 100 Cambridge Street, Boston, Massachusetts 02202	617-727-3002
Michigan	Director	Michigan Department of Agriculture, Lewis Cass Office Building, Lansing, Michigan 48913	517-373-1050
Minnesota	Commissioner	Department of Agriculture, 530 State Office Building, St. Paul, Minnesota 55101	612-221-2856
Mississippi	Commissioner	Department of Agriculture and Commerce, P.O. Box 1609, Jackson, Mississippi 39205	601-354-6563
Missouri	Commissioner	Department of Agriculture, 100 East Capitol Avenue, Jefferson State Office Building, Jefferson City, Missouri 65102	314-636-7166

State		Address	Commercial Telephone No.
Montana	Commissioner	Department of Agriculture, Capitol Annex Building, Helena, Montana 59601	406-449-3144
Nebraska	Director	Department of Agriculture, State Capitol, Lincoln, Nebraska 68509	402-471-2341
Nevada	Director	Nevada Department of Agriculture, 350 Capitol Hill Avenue, P.O. Box 1209, Reno, Nevada 89504	702-784-6401
New Hampshire	Commissioner	Department of Agriculture, State House, 107 Main Street, Concord, New Hampshire 03301	603-271-3551
New Jersey	Secretary	New Jersey Department of Agriculture, P.O. Box 1888, John Fitch Plaza, Trenton, New Jersey 08625	609-292-3976
New Mexico	Director	Department of Agriculture, P.O. Box 3189. Las Cruces, New Mexico 88001	505-646-3007
New York	Commissioner	Department of Agriculture and Markets, State Campus, Albany, New York 12226	518-457-4188
North Carolina	Commissioner	Department of Agriculture, Raleigh, North Carolina 27602	919-829-7125
North Dakota	Commissioner	Department of Agriculture, 601 Capitol Building, Bismarck, North Dakota 58501	701-224-2231
Ohio	Director	Ohio Department of Agriculture, State Office Building, Columbus, Ohio 43215	614-469-2732

State		Address	Commercial Telephone No.
Oklahoma	President	Ohio Department of Agriculture, State Capitol Building, Oklahoma City, Oklahoma 73105	405-521-3866
Oregon	Director	State Department of Agriculture, Salem, Oregon 97310	503-378-4665
Pennsylvania	Secretary	Department of Agriculture, 2301 N. Cameron Street, Harrisburg, Pennsylvania 17120	717-787-4737
Puerto Rico	Secretary	Department of Agriculture, P.O. Box 10163, Santruce, Puerto Rico 00908	809-722-2120
Rhode Island	Director	Department of Natural Resources, Veterans Memorial Building, 83 Park Street, Providence, Rhode Island 02903	401-277-2000
South Carolina	Commissioner	Department of Agriculture, Wade Hampton Office Building, P.O. Box 11980, Columbia, South Carolina 29211	803-758-2426
South Dakota	Secretary	Department of Agriculture, Pierre, South Dakota 57501	605-224-3375
Tennessee	Commissioner	Department of Agriculture, Box 40627, Melrose Station, Nashville, Tennessee 37204	615-832-6155
Texas	Commissioner	Department of Agriculture, P.O. Box 12847, Capitol Station, Austin, Texas 78711	512-475-2760

State		Address	Commercial Telephone No.
Utah	Commissioner	Department of Agriculture, 412 State Capitol Building, Salt Lake City, Utah 84114	801-328-5421
Vermont	Commissioner	Department of Agriculture, Agriculture Building, Montpelier, Vermont 05602	802-223-2311
Virgin Islands	Commissioner	Department of Agriculture, St. Croix, Virgin Islands 00820	809-772-0990
Virginia	Commissioner	Department of Agriculture and Commerce, P.O. Box 1163, Richmond, Virginia 23219	703-770-3501
Washington	Director	Department of Agriculture, General Administration Building, P.O. Box 128, Olympia, Washington 98501	206-753-5050
West Virginia	Commissioner	Department of Agriculture, State Capitol Building, Charleston, West Virginia 25305	304-348-2201
Wisconsin	Secretary	Department of Agriculture, 801 West Badger Road, Madison, Wisconsin 53702	608-266-7100
Wyoming	Commissioner	Department of Agriculture, 313 Capitol Building, Cheyenne, Wyoming 82001	307-777-7321

F. U.S. Forest Service: National Forest Regions, Research Units, and Region Offices of State and Private Forestry

National Forest Region No.	Address	National Forest Region No.	Address
1	Forest Service-USDA Federal Building Missoula, Montana 59801 Phone: 406-549-6511	6	Forest Service-USDA 319 Southwest Pine Street Portland, Oregon 97208 Phone: 505-221-3625
2	Forest Service-USDA Federal Center Building 85 Denver, Colorado 80225 Phone: 303-234-3131	8	Forest Service-USDA Suite 800 1720 Peachtree Road, N.W. Atlanta, Georgia 30309 Phone: 404-526-5177
3	Forest Service-USDA New Federal Building Albuquerque, New Mexico 87101 Phone: 505-843-2401	9	Forest Service-USDA Greyhound Building 633 West Wisconsin Avenue Milwaukee, Wisconsin 53203 Phone: 414-224-3693
4	Forest Service-USDA 324 - 25th Street Ogden, Utah 84401 Phone: 801-399-6011	10	Forest Service-USDA Juneau, Alaska 99801 Phone: 907-586-7263
5	Forest Service-USDA 630 Sansome Street San Francisco, California 94111 Phone: 415-556-4310		

Research Units

Forest Products Laboratory
Forest Service-USDA
North Walnut Street
Madison, Wisconsin 53705
Phone: 608-257-2211

Institute of Tropical Forestry
USDA-Forest Service
P.O. Box AQ
Rio Piedras, Puerto Rico 00928
Phone: 809-765-0404

Intermountain Experiment Station
Forest Service-USDA
Forest Service Building
Ogden, Utah 84401
Phone: 801-399-6361

North Central Experiment Station
Forest Service-USDA
University Farm
St. Paul, Minnesota 55101
Phone: 612-645-0841

Northeastern Experiment Station
Forest Service-USDA
6816 Market Street
Upper Darby, Pennsylvania 19082
Phone: 215-352-5800

Pacific Northwest Experiment Station
Forest Service-USDA
809 Northeast 6th Avenue
Portland, Oregon 97208
Phone: 508-234-3361

Pacific Southwest Experiment Station
Forest Service-USDA
Stead Building
1960 Addison Street
Berkeley, California 94701
Phone: 415-841-5121

Research Units

Rocky Mountain Experiment Station
Forest Service-USDA
Forestry Building
Fort Collins, Colorado 80521
Phone: 303-482-7332

Southeastern Experiment Station
Forest Service-USDA
Post Office Building
Asheville, North Carolina 28802
Phone: 707-254-0961

Southern Experiment Station
Forest Service-USDA
T-10-210 Federal Building
701 Loyola Avenue
New Orleans, Louisiana 70113
Phone: 504-527-6787

State and Private Forestry

Northeastern Area
Forest Service-USDA
6816 Market Street
Upper Darby, Pennsylvania 19082
Phone: 215-352-5800

Southeastern Area
Forest Service-USDA
Suite 800
1720 Peachtree Road, N.W.
Atlanta, Georgia 30390
Phone: 404-526-5964

G. Plant Materials Centers, Soil Conservation Service, and Cooperating Agencies

ALASKA, Star Route B, Box 357, Palmer 99645
ARIZONA, 3241 Romers Road, Tucson 85705
CALIFORNIA, P.O. Box 68, Lockeford 95237
FLORIDA, Route 2, Box 242, Brooksville 33512
GEORGIA, Box 680, University of Georgia, Americus 31709
HAWAII, P. O. Box 74, Hoolehula, Molokia 96729
IDAHO, P.O. Box AA, Aberdeen 83210
KANSAS, Route 2, P.O. Box 829, Manhattan 66502
KENTUCKY, Plant Materials Centers, Quicksand 41363
MARYLAND, Building 509, Agricultural Research Center, Beltsville
MICHIGAN, Route 1, Rose Lake, East Lansing 48824
MISSISSIPPI, P.O. Box D, Coffeeville 38922
MISSOURI, P.O. Box 108, Elsberry 63343
MONTANA, Route 1, Box 81, Bridger 59014
NEW JERSEY, P.O. Box 236-A, RD-1, Cape May Court 08210
NEW MEXICO, Route 1, Box 28, Los Lunas 87031
NEW YORK, P.O. Box 295, Route 352, Big Flats 14814
NORTH DAKOTA, P.O. Box 1458, Bismarck 58501
OREGON, 3420 Northeast Granger Avenue, Corvallis 97330
TEXAS, Route 1, Box 133-A, Knox City 75929
WASHINGTON, Johnson Hall, Washington State University, Pullman 99163

H. Transportation Research Information Service (from the Transporation Research Board, National Research Council, National Academy of Science, National Academy of Engineering)

Manager, Highway Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (Telephone: 202-961-1782).

Highway Research Information Service, Room 515, Joseph Henry Building, 2100 Pennsylvania Avenue, N.W., Washington, D.C. 20418

I. Resource Associations and Organizations

AGRONOMY

American Forage and Grassland Council
P.O. Box 48
State College, Pennsylvania 16801
Executive Secretary

American Society of Agronomy
677 South Segoe Road
Madison, Wisconsin 53711
Executive Vice President

Crop Science Society of America
677 South Segoe Road
Madison, Wsiconsin 53711
Executive Vice President

Soil Conservation Society of America
7515 Northeast Ankeny Road
Ankeny, Iowa 50021
Director

Soil Science Society of America
677 South Segoe Road
Madison, Wisconsin 53711
Executive Vice President

ARCHITECTURE

American Institute of Landscape Architects
6810 North 2nd Place
Phoenix, Arizona 85012

American Society of Landscape Architects
1750 Old Meadow Road
McLean, Virginia 22101
Executive Director

BOTANY

American Association of Botanical Gardens
and Arboreta, Inc.
Horticulture Department
New Mexico State University
Las Cruces, New Mexico 88003
Secretary-Treasurer

Botanical Society of America
Rutgers University
New Brunswick, New Jersey 08903
Secretary

CONSTRUCTION

American Land Development Association
604 Solar Building
1000 - 16th Street, N.W.
Washington, D.C. 20036

Arizona Landscape Contractors Association
326 West Cambridge Avenue
Phoenix, Arizonia 85003
Executive Secretary

Associated Landscape Contractors of America, Inc.
1750 Old Meadow Road
McLean, Virginia 22101
Executive Director

Associated Landscape Contractors of Oregon
Box 2228
Salem, Oregon 97308

Associated Landscape Designers and Contractors
702 North 65th Street
Seattle, Washington 98103

California Landscape Contractors Association, Inc.
4570 Campus Drive
Suite 8
Newport Beach, California 92660
Executive Director

Illinois Landscape Contractors Association
Box 484
Bloomingdale, Illinois 60108
Executive Secretary

Minnesota Landscape Maintenance Association, Inc.
6643 Colfax Avenue, N.
Minneapolis, Minnesota 55430
Executive Secretary

National Landscape Association
230 Southern Building
15th and H Streets, N.W.
Washington, D.C. 20005
Executive Vice President

Ornamental Growers Association
645 North Milwaukee Avenue
Wheeling, Illinois 60090
Secretary-Treasurer

Professional Landscape Contractors of Ohio
2265 Green Road
Cleveland, Ohio 44121
Historian

Texas Landscape Contractors Association
7700 Northaven Road
Dallas, Texas 75230
Director

Wisconsin Landscape Contractors Association
4209 35th Street
Milwaukee, Wisconsin 53211
Secretary-Treasurer

ECOLOGY AND ENVIRONMENT

The Conservation Foundation
1250 Connecticut Avenue, N.W.
Washington, D.C. 20005

Council on Environmental Quality
722 Jackson Place
Washington, D.C. 20006

Environmental Protection Agency
Office of Public Affairs
Washington, D.C. 20460

Keep America Beautiful, Inc.
99 Park Avenue
New York, New York
Executive Vice President

National Audubon Society
1130 5th Avenue
New York, New York 10028

National Wildlife Federation
1412 16th Street, N.W.
Washington, D.C. 20005

The Nature Conservancy
1522 K Street, N.W.
Washington, D.C. 20005

FARM EQUIPMENT

American Society of Agricultural Engineers
2950 Niles Road
St. Joseph, Michigan 49085
Executive Secretary

Farm and Industrial Equipment Institute
410 North Michigan Avenue
Chicago, Illinois 60611
Executive Secretary

Farm Equipment Manufacturers Association
230 South Bemiston
St. Louis, Missouri 63105
Executive Vice President

Farm Equipment Wholesalers Association
Suite 1100
Upper Midwest Building
Minneapolis, Minnesota 55401
Executive Director

National Farm and Power Equipment Dealers Association
2340 Hampton Avenue
St. Louis, Missouri 63139
Executive Vice President, Dealer
  Business Management Services

FERTILIZERS

Association of American Plant Food Control Officials, Inc.
Department of Biochemistry
Purdue University
West Lafayette, Indiana 47907
Secretary

Association of Official Analytical Chemists
P.O. Box 540
Benjamin Franklin Station
Washington, D.C. 20044
Executive Secretary

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Washington, D.C. 20036
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Manufacturing Chemists Association
1825 Connecticut Avenue, N.W.
Washington, D.C. 20009
Vice President, Secretary-Treasurer

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President

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1649 Tullie Circle, N.E.
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St. Joseph, Michigan 49085
Executive Director

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99 Church Street
New York, New York 10007
Secretary-Treasurer

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230 Southern Building
Washington, D.C. 20005
Executive Vice President

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Irrigation Technical Services
P.O. Box 268
Lafayette, California 94549

Sprinkler Irrigation Association
Suite 310
13975 Connecticut Avenue
Silver Spring, Maryland 20906

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860 Terrace Acres
Auburn, Alabama 36830
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230 Southern Building
Washington, D.C. 20005
Executive Vice President

American Nurserymen's Protective Association
Rural Route 2
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Indianapolis, Indiana 46231
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American Rock Garden Society
90 Pierpont Road
Waterbury, Connecticut 06705
Secretary

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326 West Cambridge
Phoenix, Arizona 85003
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First Western Bank Building
1005 Eighth Street
Sacramento, California 95814
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1568 Carling Avenue
Ottawa, Canada K1Z 7M5
Executive Vice President

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1814 South Meade
Denver Colorado 80219
Executive Secretary

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P.O. Box 352
West Haven, Connecticut 06516
Executive Secretary

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Box 306
Selbyville, Delaware 19975
Secretary

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101 Executive Boulevard
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Executive Director

Florida Nurserymen and Growers Association
2016 Southwest 27th Terrace
Fort Lauderdale, Florida 33312
Executive Secretary

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Athens, Georgia 30601
Executive Secretary

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107 Lakeview Avenue, N.E.
Atlanta, Georgia 30305

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Boise, Idaho 83702
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Wheeling, Illinois 60090
Secretary

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West Lafayette, Indiana 47907
Executive Secretary

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Ankeny, Iowa 50021
Executive Secretary

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Ottawa, Kansas 66067
Secretary

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Kentucky Agricultural Experiment Station
University of Kentucky
Lexington, Kentucky 40506
Secretary

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Mentor, Ohio 44060
Secretary

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Box 4492
University of Southwestern Louisiana
Lafayette, Louisiana 70501
Secretary

Maryland Nurserymen's Association
Joppa Road
Perry Hall, Maryland 21128
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715 Boylston St.
Boston, Massachusetts 02116
Executive Director or
Associate Director

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Wayne, Michigan 48184
President

Michigan Association of Nurserymen
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Lansing, Michigan 48910
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3481 East 10th Street
Sioux Falls, South Dakota 57103

Minnesota Nurserymen's Association
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Hastings, Minnesota 55033
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Mississippi State University
P.O. Box 5425
State College, Mississippi 39762
Secretary-Treasurer

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233 Timbercrest Road
Kirkwood, Missouri 63122
Executive Secretary-Treasurer

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Bozeman, Montana 59715
Secretary

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230 Southern Building
Washington, D.C. 20005
Administrator

Nebraska Association of Nurserymen
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Lincoln, Nebraska 68506
Secretary-Treasurer

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Federal Station
Las Vegas, Nevada 89101
President

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West Haven, Connecticut 06516
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RFD 2
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Rutgers University
New Brunswick, New Jersey 08903
Secretary

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101 Executive Boulevard
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Executive Director

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Box 5023
College Station
Raleigh, North Carolina 27607
Secretary

North Dakota Nurserymen's Association
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South Fargo, North Dakota 58102
Secretary

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1540 West 5th Avenue
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Executive Secretary

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Oklahoma City, Oklahoma 73127
Secretary

Oregon Association of Nurserymen, Inc.
12750 Southwest Pacific Highway
Portland, Oregon 97223
Executive Secretary

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Hilltop and Ridge Roads
Boiling Springs, Pennsylvania 17007
Executive Director

Rhode Island Nurserymen's Association
339 Woodward Hall
University of Rhode Island
Kingston, Rhode Island 02881
Secretary

South Carolina Nurserymen's Association
Horticulture Department
Clemson University
Clemson, South Carolina 29631
Executive Secretary

South Dakota Nurserymen's Association
P.O. Box 1014
Aberdeen, South Dakota 57401
Secretary-Treasurer

Southern Nurserymen's Association
3813 Hillsboro Road
Room 227
Nashville, Tennessee 37215
Executive Secretary

Tennessee Nurserymen's Association
P.O. Box 57
McMinnville, Tennessee 37110
Executive Secretary

NURSERY AND LANDSCAPING (Continued)

Texas Association of Nurserymen
512 East Riverside Drive
Suite 207
Austin, Texas 78704
Executive Vice President

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3500 South 9th East
Salt Lake City, Utah 84106
Executive Secretary

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South Charleston, West Virginia 25309
President

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Executive Secretary

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Salem, Oregon 97303

Oregon Chewings and Creeping Red Fescue Commission
1349 Capitol Street, N.E.
Salem, Oregon 97303

Society of Commercial Seed Technologists
Colborn Seed Testing Service
2600 Woods Boulevard
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Manhattan Ryegrass Growers Association
P.O. Box 145
Hubbard, Oregon 97032

NURSERY AND LANDSCAPING (Continued)

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President

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Washington, D.C. 20036
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Mount Vernon, Virginia 22121

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1010-16th Street, N.W.
Washington, D.C. 20036

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P.O. Drawer S,
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College Park, Maryland 20740
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Burien, Washington 98166

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850 Wrigley Building, N.
410 North Michigan Avenue
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Executive Plaza Building
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Suite 903-05
1725 K Street, N.W.
Washington, D.C. 20006
Executive Director

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P.O. Box 7256
Belle View Station
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Portland, Oregon 97213
Executive Secretary

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Seed Laboratory
University of Kentucky
Lexington, Kentucky
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101 Park Avenue
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Better Lawn and Turf Institute
Route 4
Kimberdale
Marysville, Ohio 43040
Director

Central Plains Turfgrass Foundation
Waters Hall
Kansas State University
Horticulture
Manhattan, Kansas 66506
Secretary-Treasurer

Chewings Fescue and Creeping Red Fescue Commission
1349 South Capitol Street, N.E.
Salem, Oregon 97303
Executive Secretary

SEED/SOD (Continued)

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College of Agriculture and Environmental Science
Rutgers University
New Brunswick, New Jersey 08903
Secretary

Delaware Turfgrass Association
Agriculture Hall
University of Delaware
Newark, Delaware 19711

Florida Turfgrass Association
903 Lee Road
Orlando, Florida 32810
Executive Secretary

Garmo, Inc.
Association Building
9th and Minnesota
Hastings, Nebraska 68901

Highland Colonial Bentgrass Commission
Department G
Suite 1
Rivergrove Building
211 Front Street, N.E.
Salem, Oregon 97303

Sod Growers Association of Michigan
60 Rush Lake Road
Pickney, Michigan
Secretary

Merion Bluegrass Association
101 Park Avenue
Room 607
New York, New York 10017
Public Relations Director

New Jersey Turfgrass Association
P.O. Box 359
Springfield, New Jersey 07081
President

Oklahoma Turfgrass Research Foundation, Inc.
115 Life Science East,
Oklahoma State University
Stillwater, Oklahoma 74074
Executive Secretary

Oregon Highland Colonial Bentgrass Commission
2111 Front Street, N.E.
Salem, Oregon 97303

Oregon Ryegrass Growers Seed Commission
2111 Front Street, N.E.
Salem Oregon 97303

Source: "Grounds Maintenance," Intertec Publishing Corporation, Kansas City, Missouri, December 1973.

J. Selection and Limitations of Mulching Materials for Stabilizing Critical Areas[1]

1. Introduction: The most effective way to stabilize a critical area is to establish plants quickly. Mulching nearly always shortens the time required to establish a suitable plant cover by reducing evaporation, moderating soil temperatures to promote germination and seedling growth, preventing crusting, and controlling wind and water erosion.

Any substance spread, formed, or left on the soil surface may act as a mulch. There is an infinite variety of mulching materials: straw, hay, and other crop residues, sawdust, woodchips, wood fiber, bark, manure, brush, jute or burlap, gravel, stones, peat, paper, leaves, plastic film, and various organic and inorganic liquids--and this is not a complete list.

Mulching helps stabilize critical areas by improving plant establishment, through conserving moisture, moderating temperatures, preventing surface crusting, and reducing erosion. Among the many materials suitable for mulching, crop residues such as straw and hay generally are the most available, economical, and commonly used. The standard amount is 1-1/2 to 2 tons of straw per acre. A variety of wood residues, including woodchips, bark, excelsior, and cellulose fiber, are available as mulching materials. Several petroleum products, such as asphalt and resin-in-water emulsions, are useful as mulches for establishing vegetation. Also available for special situations are plastic films, gravel, stones, manure, jute, peat, and paper. Selection depends on characteristics of the area to be stabilized and the availability, cost, and properties of the mulch material.

Investigations in New Mexico have shown the advantages of mulching for establishing perennial species. For summer seeding near Santa Fe, the most effective mulch material was straw or a white petroleum resin; these materials reduced moisture losses and lowered mid-afternoon temperatures in the top inch of soil during the time seeds were germinating and seedlings emerging.

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[1] Presented by H. W. Springfield, Range Scientist, Rocky Mountain Forest and Range Experiment Station, Albuquerque, New Mexico, at the Critical Area Stabilization Workshop of the New Mexico Interagency Range Committee, in Albuquerque, New Mexico, 27-29 April 1971. Reproduced without change (except for handbook style conformity), including literature cited.

How effective a mulch will be depends on many factors, including physical and chemical properties of the soil, land-forming or cultural practices, and characteristics of the mulch itself, such as color, roughness, and manner of application (Qashu and Evans, 1967).[1/] The effect of color and roughness of the soil surface are directly related to the radiation balance at the surface and, consequently, heat transfer in the soil. Slope, aspect, and orientation of the soil surface influence the solar energy received. Other considerations are steepness and length of slope, soil texture and depth, rate of application of the mulch, and weather before, during, and after application.

2. Mulch materials and application: Materials for mulching will be discussed in the following order: crop residues, wood residues, petroleum products, latex emulsions, plastic films, gravel, stones, and other materials.

a. Crop residues: Crop residues undoubtedly are the most widely used mulching materials. They may be produced in place or hauled in.

A special category of crop residues are those produced in place, such as stubble mulch and no-tillage cropping. For some situations the most practical method for stabilizing the soil is to grow an annual crop like sorghum and convert it to a temporary mulch in place. Bartee (1964)[2/] reported "dead litter mulch" effective for establishing vegetation on floodwater-retarding structures in Texas; he found by mowing the sorghum to a height of 6 to 10 in., the mulch material was distributed evenly over the area and the stalks kept the cut material from blowing away. A disadvantage is that this type of mulch cannot be established in all seasons, or on all areas.

[1/] Qashu, H. K., and D. D. Evans, "Effect of Black Granular Mulch on Soil Temperature, Water Content, and Crusting," Soil Science Society of America Proceedings, 31:429-435, (1967).

[2/] Bartee, L. D., "Evaluation of Mulch Materials for Establishing Vegetation on Small Dams," Journal of Soil and Water Conservation, 19:117-118 (1964).

The crop residues most commonly used as mulch are wheat straw and native hay, hauled in (Chepil et al., 1963[1]). Either oat or barley straw is as effective as wheat straw, and tame hay is as good as wild hay. The material should be free of seeds. As a rule, the best mulch is the one most available and nearest. A fine-stemmed baled mulch is preferable to a loose mulch for mechanical spreading. Beater-type mulch spreaders work well on level areas, but a blower-type is best for steep slopes. Methods that require the least hand labor usually prove most economical. Regardless of the material or method, the mulch should be spread uniformly. Baled material tends to fall in bunches unless it is cut or shredded, and scattered or blown with force. The average length of cut stems should not be less than 6 in. if the mulch is to be anchored mechanically. Brush usually has to be spread by hand, though a mechanized procedure has been developed (Herbel, 1971[2]); an advantage of brush as mulch is its slow decomposition.

Straw and hay mulches should be anchored. According to Chepil et al. (1963) the best mechanical equipment is a disk packer. Cook et al. (1970)[3] reported a straw can be held in place by punching it into the soil with a mulch tiller, a modified sheepsfoot roller, or a weighted farm disk. Chemical agents, such as asphalt, may be used to anchor straw or hay. The liquid asphalt spray usually is injected directly into the stream of mulch as it comes out of the spreader.

In a classical experiment, Russel (1940)[4] exposed moist soil to different conditions for 4 days during the summer; relative losses were:

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[1] Chepil, W. S., N. P. Woodruff, F. H. Siddoway, and D. V. Armbrust, "Mulches for Wind and Water Erosion Control," Agricultural Research Service, ARS 41-84, 23 pages (1963).

[2] Herbel, C. H., "Environmental Modification for Seedling Establishment," In: The Biology and Utilization of Grass, V. Youngner and C. McKell, Ed., Academic Press, Inc., New York, in press (1971).

[3] Cook, C. W., I. B. Jensen, G. B. Coltharp, and E. M. Larson, "Seeding Methods for Utah Roadsides," Utah Agricultural Experiment Station Resources Series 52, 23 pages, illustrated, (1970).

[4] Russel, J. C., "The Effect of Surface Cover on Soil Moisture Losses by Evaporation," Soil Science Society of America Proceedings (1939) 4:65-70 (1940).

Bare soil	100%
Bare soil shaded from sun	64%
Bare soil shaded from sun and wind	47%
Straw mulched (1-1/2 in. thick)	27%

Russell concluded that half the effect of the straw mulch was due to obstruction of solar radiation.

More recent research has clearly demonstrated the value of straw as a mulch material. Straw mulches proved superior to several manufactured mulches for establishing turf on roadside slopes in Michigan (Beard, 1966[1/]). Straw alone, straw plus asphalt, and mulchnet over straw were better than Soil Gard, Erosionet, and jute net. Though the manufactured mulches provided initial protection against erosion, they failed to retain sufficient soil moisture for grass establishment.

For establishing plants on highway banks in Georgia, 2 tons of straw per acre proved superior to jute, water-soluble latex, plastic film, sawdust, or no mulch (Richardson and Diseker, 1965[2/]). Further studies in Georgia showed 2 tons of straw per acre adequately protected newly seeded 40% backslopes when subjected to 1.3 in. of rain in 30 min (Barnett et al., 1967[3/]). When the slopes received 2.7 in. of rain in 60 min, two treatments stood out as best: (a) the "whisker dam" or Florida method, where the straw is pressed into loose soil by a 3-ft-diameter roller equipped with blunt coulters 8 to 12 in. apart, and (b) the Cartersville method where after seeding, the area is cultipacked and covered with straw at the rate of 2 tons/acre. In all cases where asphalt spray was part of the treatment, the effectiveness of the mulch was decreased.

1/ Beard, J. B., "A Comparison of Mulches for Erosion Control and Grass Establishment on Light Soil," Michigan Agricultural Experiment Station Quarterly Bulletin, 48:369-376 (1966).

2/ Richardson, E. C., and E. G. Diseker, "Establishing and Maintaining Roadside Cover in the Piedmont Plateau of Georgia," Agronomy Journal, 57:561-564 (1965).

3/ Barnett, A. P., E. G. Diseker, and E. C. Richardson, "Evaluation of Mulching Methods for Erosion Control on Newly Prepared and Seeded Highway Backslopes," Agronomy Journal, 59:83-85 (1967).

On backslopes in South Dakota, water infiltration was faster and erosion much less from plots mulched with 1-1/2 tons of straw per acre, compared with unmulched plots (Hovland et al., 1966[1]); but stands of perennial plants did not develop due to competition from grain seedlings that grew from seeds in the straw. In Utah, straw at 1-1/2 tons/acre anchored with asphalt at 300 gal/acre gave good results, but Cook et al. (1970) pointed out this mulch is susceptible to being carried away by wind and water. In Texas, prairie hay or straw at 1-1/2 tons/acre applied with 0.05 gal/yard^2 of asphalt effectively conserved moisture and protected the soil (McCully and Bowmer, 1969[2]).

For stabilizing coal spoil banks in Wyoming the most effective treatment was seeding, then mulching with straw and jute netting (Jacoby, 1969[3]). Straw alone resulted in denser seedling stands than jute alone. For reducing soil losses from newly constructed backslopes in the Pacific Northwest, straw mulch at the rate of 2 tons/acre over grass-legume mixtures were found essential (Dyrness, 1970[4]).

In the Australian alps, fine meadow hay applied at 2-1/3 to 3 tons/acre and anchored with asphalt proved effective on 2:1 slopes (Clothier and Condon, 1968[5]). The asphalt emulsion (anionic, medium setting) was applied at 400 to 500 gal/acre; this high rate was necessary due to strong winds in the alpine and subalpine environment.

On 15% slopes in Indiana, mulch rates of 1/4 and 1/2 ton/acre reduced soil losses to less than a third of those from unmulched areas (Meyer et al., 1970[1/]). A 1-ton/acre rate decreased soil loss to only a sixth of that from no mulch. Runoff velocity for the 1/4-ton rate was only half that for no mulch.

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[1] Hovland, D., D. E. Wesley, and J. Thomas, "Establishing Vegetative Cover to Protect Roadside Soils in South Dakota," South Dakota Agricultural Experiment Station Bulletin No. 527, 31 pages, illustrated (1966).

[2] McCully, W. G., and W. J. Bowmer, "Erosion Control on Roadsides in Texas," Research Report 67-8 (final), Texas Transportation Institute, 33 pages, illustrated (1969).

[3] Jacoby, P. W., "Revegetation Treatments for Stand Establishment on Coal Spoil Banks," Journal of Range Management, 22:94-97, illustrated (1969).

[4] Dyrness, C. T., "Stabilization of Newly-Constructed Road Backslopes by Mulch and Grass-Legume Treatments," USDA Forest Service Research Note PNW-123, 5 pages, Pacific Northwest Forest and Range Experiment Station (1970).

[5] Clothier, D. P., and R. W. Condon, "Bitumen-Straw Mulching for Better Stabilization on the Kosciusko Road. New South Wales," Soil Conservation Service Journal, 24:218-230 (1968).

b. Wood residues: Sawdust, woodchips, bark, and shavings constitute an abundant source of mulching material in many areas. Wood residues such as these not only protect the soil surface but also add organic matter. As a general rule, supplemental nitrogen (N) should be applied with wood residue mulches.

In evaluating wood residues for mulching it is important to consider particle-size distribution, carbon (C):N ratio, composition, and rate of decomposition (Bollen and Glennie, 1961[2/]). Advantages of wood residues are: they are easier to apply, longer lasting, and less susceptible to blowing or fire than straw or hay. Disadvantages are competition for available N, decrease of pH if the material is strongly fermented, and packing of fine particles. Chips, shavings, and millrun sawdust make good mulch, but re-saw sawdust packs tightly and may retard aeration and infiltration. If the C:N ratio exceeds 25:1, microorganisms carrying on decomposition will compete with plant roots for available N. Bark is available from most primary wood manufacturing operations and sawdust is available at most sawmills; both are very low in N, however (Basham and Thompson, 1967[3/]):

	pH	N (%)
Wood	5.2	0.1
Bark	3.6	0.2
Peat	3.8	0.8

[1/] Meyer, L. D., W. H. Wischmeier, and G. R. Foster, "Mulch Rates Required for Erosion Control on Steep Slopes," Soil Scientist Society of America Proceedings, 34:928-931 (1970).

[2/] Bollen, W. B., and D. W. Glennie, "Sawdust, Bark, and Other Wood Wastes for Soil Conditioning and Mulching," Forest Products Journal, 11:38-46 (1961).

[3/] Basham, B. M., and W. S. Thompson, "An Economic Study of the Production and Use of Sawdust and Bark as Mulches and Soil Amendments for Horticultural and Agricultural Purposes," Mississippi Forest Products Laboratory Information Series No. 6, 25 pages (1967).

Neither bark nor sawdust has any long-term effect on soil pH, which can be maintained near neutral by applying 10 lb of lime per cubic yard of wood residue. For bark, a screened grind ranging from 1/2 in. to fines, with most particles 1/50 to 1/8 in., is satisfactory for mulching. The C:N ratio can be adjusted to near 25:1 by adding 5 to 10 lb of fertilizer N per ton of bark.

Bark has a potentially important use as a soil stabilizer for highway banks and other slopes (Bolen, 1969[1/]); it could be applied economically with suitably designed hydraulic spreading equipment.

Another wood residue mulch is excelsior or shredded wood chopped in 8-in. lengths which can be applied with or without asphalt at the rate of 2 tons/acre (Thompson and Palmertree, 1967[2/]). Green wood excelsior fibers 4 to 6 in. long applied at 2 tons/acre with a mulch blower provided good soil protection on 3:1 slopes in Minnesota (Foote et al., 1966[3/]). This long-fibered wood mulch proved as good as straw plus asphalt and had the advantage over straw of not requiring anchoring. Both the excelsior and straw were superior to short-fibered wood cellulose pulps, applied hydraulically, for soil protection and plant establishment. Excelsior applied at 1-1/2 tons/acre, and held in place by 0.05 gal/yard^2 of asphalt, was less effective than prairie hay but better than woodchips or asphalt as mulch for roadside seeding in Texas (McCully and Bowmer, 1969). If applied as a mat, excelsior was expensive, laborious to apply, decomposed rather rapidly, and attracted mice which fed on the seedlings in Utah (Cook et al., 1970).

Wood cellulose fiber, available commercially in bales, usually is mixed with water and seed to form a slurry, which is sprayed with a hydroseeder. Bartee (1964) reported wood fiber at the rate of

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[1/] Bollen, W. B., "Properties of Tree Barks in Relation to Their Agricultural Utilization," USDA Forest Service Research Paper PNW-77, 36 pages, illustrated, Pacific Northwest Forest and Range Experiment Station (1969).

[2/] Thompson, W. R., and H. D. Palmertree, "Mulches Improve New Turf Stands," Weeds, Trees and Turf, 6:48, 50 (1967).

[3/] Foote, L. E., B. F. Himmelman, and D. L. Kill, "Vegetation and Erosion Control," Minnesota Department of Highways, Investigation No. 614, Interim Report, 39 pages, illustrated (1966).

330 lb/1,000 gal. of water per acre was effective in establishing vegetation on eroded soils in Texas. In Utah, wood fiber at 1,500 lb/acre gave consistently good results except where there was frost heaving or excessive surface water flow (Cook et al., 1970). If applied at less than 1,000 lb/acre, or on steep, unstable slopes, little benefit was obtained.

c. Petroleum products: Several petroleum products are suitable as agricultural mulches. Specially formulated emulsions of asphalt, known under various trade names, have been used throughout the world to reduce evaporation, prevent soil crusting, promote seed germination, and advance the seeding date. The film clings to, but does not penetrate deeply into the soil; is not readily destroyed by wind or rain; and remains intact 4 to 10 weeks or longer (Black and Popkin, 1967[1]).

Chepil et al. (1963) identified cutback asphalts and asphalt emulsions. Slow, medium, and rapid-curing materials are available for cutbacks, whereas the asphalt-in-water emulsions usually are rapid setting. Asphalts for surface films should be slow curing or slow setting to allow grass seedlings to break through the film more easily. A rapid-setting kind is needed for anchoring straw. Heating is required to make concentrated cutback sprayable and is usually needed with asphalt emulsion too. The undiluted asphalt emulsion is somewhat less effective in controlling erosion than the undiluted cutback asphalt. Asphalt films are virtually nonporous and consequently much of the rainwater runs off. Therefore seeds may fail to germinate if insufficient soil moisture is present before the asphalt is applied. According to Chepil et al. (1963) the rate of application to control erosion should be 1/4 gal/yard^2 (1,200 gal/acre). An asphalt emulsion applied at this rate on sandy soils will go through the winter nearly intact, but the film will disintegrate within 2 weeks to 3 months on silty clay or clay due to the swelling and shrinking of the soil. Cutback asphalt films, on the other hand, are more resistant to weathering and will remain intact 6 to 12 months.

The ideal film, according to Chepil et al. (1963), is stable against erosion, sufficiently porous to allow water to enter, yet insoluble in water and resistant enough to the weather that it lasts until permanent vegetation becomes established. Next to well-anchored straw or hay, the resin in water emulsion comes closest to meeting these requirements.

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[1] Black, J. F., and A. H. Popkin, "New Roles for Asphalt in Controlling Man's Environment," Presentation at Annual Meeting, National Petroleum Refiners Association, San Antonio, Texas, 3-5 April 1967.

Resin-in-water emulsions are stable and can be diluted with large quantities of water without breaking the emulsion. The resins resist weathering and soil bacteria. The emulsion leaves the surface permeable to water and stabilizes the soil against erosion by wind or water. The film is stable on sandy soils but breaks up within a few weeks on silty clay or clay soil. Seedlings emerge better through resin-in-water film than through asphalt or latex films. Resin-in-water emulsion diluted 1:1 with water should be applied at the rate of 1/8 gal/yard^2 (600 gal/acre) to protect loamy sands or sandy loams against wind erosion (Chepil et al., 1963).

Petroleum mulches have been found useful under a variety of environmental conditions and for a variety of purposes. Results of more than 100 field trials in Italy, England, and Trinidad showed asphalt mulch markedly reduces moisture losses by evaporation, protects the soil surface from rain damage, and reduces erosion (Jordan and Sampson, 1966[1]). Adams (1967)[2] claims petroleum mulch film is pliable, readily penetrated by seedlings, disintegrates within several months, and is metabolized by soil microorganisms.

Based on rangeland studies in eastern Colorado, Bement et al. (1961)[3] concluded the net effect of asphalt mulch on plant establishment varied with species and kind of asphalt. They recommended the reaction of a given species to an asphalt mulch be checked. They also reported that high intensity storms tended to break up the asphalt film and reduce its effectiveness.

A smooth surface containing a minimum of coarse fractions requires less material and results in a better film (Cannon, 1966[4]). Compaction of the surface soil before spraying the asphalt has been reported to be beneficial (Johnson et al., 1966[5]).

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[1] Jordan, D., and A. J. Sampson, "Crop Responses to Bitumen Mulches," Span, 9:157-160 (1966).

[2] Adams, J. E., "Effect of Mulches and Bed Configuration. I. Early-Season Soil Temperature and Emergence of Grain Sorghum and Corn," Agronomy Journal, 59:595-599 (1967).

[3] Bement, R. E., D. F. Hervey, A. C. Everson, and L. O. Hylton, Jr., "Use of Asphalt-Emulsion Mulches to Hasten Grass-Seedling Establishment," Journal of Range Management, 14:102-109 (1961).

[4] Cannon, M. D., 'Synthetic Strip Mulches," Western Farmers Equipment, 63:FMW13-FMW14 (1966).

[5] Johnson, W. H., O. K. Hedden, and J. D. Wilson, "How Liquid Mulches Affect Moisture Retention, Temperature, and Seedling Growth," Agricultural Engineering, 47:196-199 (1966).

Because the asphalt is in direct contact with the soil, the thicker the film, the more effective it is in reducing evaporation and the higher the soil temperature if the asphalt is dark colored (Collis-George et al., 1963[1]). But if the application rate is too high, the film may prevent seedlings from breaking through (Johnson et al., 1966). The best coating may be one that suppresses evaporation, but does not necessarily eliminate vapor movement; coatings with minute cracks proved effective under certain conditions (Gerald and Chambers, 1967[2]).

For roadside seeding in Texas, McCully and Bowmer (1969) reported asphalt applied at 0.2 gal/yard^2 was less effective than prairie hay or excelsior. Asphalt was not effective for roadside seeding in Utah because the solar heat absorbed by the asphalt was lethal to fragile grass seedlings, according to Cook et al. (1970).

d. Latex emulsions: These are elastomeric polymer emulsions that, when diluted with water and sprayed on the soil, produce a rubbery film resistant to erosion (Chepil et al., 1963). The emulsion breaks readily on contact with the soil and therefore does not penetrate the surface readily. The film limits movement of water into the soil.

In dryland cotton studies, Soil Gard (a latex emulsion) applied as a liquid spray (1 part to 9 parts water) at the rate of 1,000 gal/acre resulted in emergence of seedlings as good as from conventional procedures and the results were less variable; but the yield increases were not sufficient to justify the cost (Batchelder and Porterfield, 1967[3]).

In mulching to establish a cover on newly constructed roadside slopes in Michigan, Beard (1966) found seedling stands were poorer where Soil Gard was used. Soil Gard also provided less erosion control than other mulches.

e. Plastic films: Mulching with plastic films has increased considerably over the past few years, generally in the production of high-value crops. Plastic mulch is an excellent vapor barrier and prevents the normal evaporation of water from the soil surface (Smith et al., 1967[1]). With a plastic mulch, the drying front that normally progresses from the surface downward is arrested, and the result is a more uniform distribution of moisture throughout the soil profile.

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[1] Collis-George, N., B. G. Davey, D. R. Scotter, and D. R. Williamson, "Some Consequences of Bituminous Mulches," Australian Journal of Agricultural Research, 14:1-11 (1963).

[2] Gerard, C. J., and G. Chambers, "Effect of Reflective Coatings on Soil Temperatures, Soil Moisture, and the Establishment of Fall Bell Peppers," Agronomy Journal, 59:293-296 (1967).

[3] Batchelder, D. G., and J. G. Porterfield, "Applying Mulches for Improving Seedling Establishment," American Society of Agricultural Engineers Transactions (ASAE), 10:625-627 (1967).

Information concerning the effects of plastic mulches on soil temperature is contradictory. Thus, some investigators have reported an increase in soil temperature with black plastic, some reported a decrease, and others report no change. Apparently the effect varies with placement. If the black plastic is in direct contact with the ground, most of the heat will be absorbed by the soil. But if there is an insulating air layer under the black plastic, the surface soil may be no warmer than bare soil (ARS, 1961[2]).

Translucent film operates like a greenhouse by transmitting insolation which is converted to sensible heat at the soil surface. White- and aluminum-pigmented films reduce soil temperatures by reflecting incident sunlight.

Exposure for 6 months to weather conditions in central Arizona seriously degraded clear, orange, and white polyethylene (1 mil), but the black still performed effectively (Gliniecki, 1959[3]). After 12 months exposure, the 1-mil black had deteriorated but 3-mil black remained durable.

In southern New Mexico, a mulch of perforated white polyethylene (1 mil) applied over seeded rows gave better stands than unmulched; the better stands were attributed to more favorable soil moisture and temperature conditions (Herbel, 1971). On hot, sunny days, soil temperatures at the 0.5-in. depth were 10 to 18° cooler under the white plastic.

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[1] Smith, E. M., R. W. Skaggs, and J. H. Casada, "Potential Field for Heat Transfer in Soil Covered by Different Plastic Mulches," American Society of Agricultural Engineers, Paper No. 67-101, 16 pages (1967).

[2] United States Agricultural Research Service, "Applied Mulches and Mulching," ARS 22-71, 12 pages (1961).

[3] Gliniecki, V. L., "Evaluating Polyethylene Films for Agriculture," Down to Earth, 15:7-9 (1959).

f. Gravel, stones, and other materials: Gravel, stones, and crushed rock have an advantage over most other mulches--they are permanent; if the individual pieces are no smaller than 1/2 in. in diameter, they will withstand a wind velocity of 85 mph (Chepil et al., 1963). But to control wind erosion the pieces must almost cover the soil surface. The finer the gravel, the less required to cover the ground.

Experiments in Colorado by Corey and Kemper (1968)[1] indicate a gravel mulch on a fallow surface is the most promising method for increasing infiltration of precipitation. These investigators point out, "No device has been conceived which can prevent entirely the exit of water from the soil surface, while at the same time permitting it to pass into the soil."

Studies during the growing season in Kansas showed a 1-in. layer of gravel painted with flat black paint had the highest net radiation, followed in order by clear plastic, bare soil, straw, and aluminum-painted gravel (Hanks et al., 1961[2]). Soil temperature (3/8 in.) was highest under clear plastic, followed by bare soil, black gravel, aluminum gravel, and straw. Evaporation was greatest from bare soil but about the same for the mulch treatments.

For seeding roadsides in Utah, gravel 3/4 to 2 in. in diameter applied to a 2-in. depth controlled surface erosion and promoted consistent stands of grass (Cook et al., 1970).

Manure, which might be a special category, often has more value as a mulch than as a source of plant nutrients. On 10 to 12% slopes in Ohio, erosion measured 0.5 ton/acre where mulched with manure compared to 12.5 tons/acre where unmulched (ARS, 1961). Manure mulch also has been found to reduce blowing of sandy soil.

Jute netting, used for stabilizing very steep roadbanks, may be considered a mulch material. It consists of a netting of woven jute twine, packaged in blanket-type rolls and held on the surface by wire staples (Thompson and Palmertree, 1967). Tested for establishing a plant cover on coal spoil banks in Wyoming, jute netting alone was less effective than straw alone; a combination of these two mulches gave the best results (Jacoby, 1969). For establishing a cover on newly constructed roadside slopes in Michigan, jute netting was not as good as straw alone or straw plus asphalt (Beard, 1966). In Utah, jute netting was effective and long-lasting, but expensive and laborious to apply; moreover, where the netting is not properly applied water will run underneath and create gullies (Cook, et al., 1970).

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[1] Corey, A. T., and W. D. Kemper, "Conservation of Soil Water by Gravel Mulches," Colorado State University Hydrology, Paper No. 30, 23 pages (1968).

[2] Hanks, R. J., S. A. Bowers, and L. D. Bark, "Influence of Soil Surface Conditions on Net Radiation, Soil Temperature, and Evaporation," Soil Science, 41:233-238 (1961).

Bran mixed with a seed-fertilizer slurry and applied with a hydroseeder provided a good mulch cover on fill slopes in Connecticut (Button and Potharst, 1962[1/]). Bran mixed with wood fiber in a 4:3 ratio produced an excellent cover that showed no signs of deterioration after 90 days.

Applying black granular coke on sandy soil near Tucson resulted in higher soil temperatures, higher soil moisture, and a friable soil surface compared with a rigid crust where not mulched (Qashu and Evans, 1967).

In Mississippi, Thompson and Palmertree (1967) applied fiberglass as a mulch with special compressed air equipment at the rate of 100 lb/100 yards^2.

In Utah, macerated paper, produced by passing newspaper through a hammermill and applied as a slurry at 1,500 lb/acre, gave satisfactory results but was not as long-lasting as straw-asphalt or wood fiber (Cook et al., 1970).

Final selection of a mulch material will depend on several considerations: (a) characteristics of the area that needs to be stabilized, such as size, shape, slope, aspect, roughness, physical and chemical properties of the soil, and precipitation, temperatures, and wind; (b) species of plants to be seeded and their requirements for germination, seedling emergence, and establishment; (c) characteristics of the mulch material itself, including color, durability, availability and cost; (d) needs for special equipment and costs of application.

3. Mulching to improve plant establishment in New Mexico: Establishment of plants by direct seeding on critical areas is an uncertain practice in all except the wetter parts of New Mexico due to erratic, unpredictable, and insufficient precipitation. Because the seeds of most plant species must be planted only an inch deep or less, they

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[1/] Button, E. F., and K. Potharst, "Comparison of Mulch Materials for Turf Establishment," Journal of Soil and Water Conservation, 17: 166-169 (1962).

are subjected to severe stresses. The moisture and temperature conditions required for seed germination and seedling emergence rarely occur naturally for more than a few days in succession. Some form of environmental modification is needed to insure success in revegetating deteriorated or disturbed areas. Mulches offer possibilities for accomplishing the necessary modification in environmental factors, especially moisture and temperature.

Several investigations in southern New Mexico have shown the advantages of mulching for establishing perennial forage species (Herbel, 1971). A mulch of white polyethylene perforated over seeded rows gave an excellent stand of grass seedlings compared to only a sparse stand in check rows. Soil temperatures in the seed zone were 10 to 18°F cooler in hot, sunny weather, and soil moisture remained adequate for more days under the white film. A mulch of uprooted brush plants deposited by special equipment over seeded strips also proved effective. The brush mulch resulted in more soil moisture, lower temperatures, and better stands of grass.

Mulching has been studied in central New Mexico from 1965 to 1970 as a method for establishing four-wing saltbush (*Atriplex canescens*) and winterfat (*Eurotia lanata*). Results of preliminary tests in 1965 and 1966 near Corona and Magdalena showed better plant establishment where a light layer of native grass was applied over seeded rows (Springfield, 1970[1]).

In a series of experiments at Santa Fe from 1967 to 1970, several mulches were compared under different weather conditions. The basic idea in these tests was to plant the seed in moist soil, then apply a mulch that would delay soil moisture losses and provide near-optimum temperatures in the seed zone. Procedures for all experiments were similar. Seeds were planted shallow--four-wing saltbush, 1/2 in. deep; winterfat, 1/16 to 1/8 in.--in moist soil at the rate of 15 viable seeds per foot of row. Mulches applied immediately after seeding were:

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[1] Springfield, H. W., "Germination and Establishment of Four-Wing Saltbush in the Southwest," USDA Forest Service Research Paper RM-55, 48 pages, illustrated, Rocky Mountain Forest and Range Experiment Station.

straw, aluminized asphalt,[1] WPR (white petroleum resin),[1] and Soil Gard.[2] Soil moisture was determined gravimetrically in 1967 and 1968 and by gypsum blocks in 1969 and 1970. Soil temperatures were measured by thermistors placed in test rows at the same level as the seeds.

In 1967, four-wing saltbush seeds were planted and mulches applied 10 July. Seedlings began emerging 18 July and reached maximum stands 28 August:

	Number of Seedlings per Foot
Straw	3.6
Aluminized asphalt	2.7
No mulch	0.7
Soil Gard	0

During the first 2 weeks, the soil was consistently more moist in mulched than in unmulched rows. Mid-afternoon soil temperatures were 20 to 25° cooler in straw-mulched rows than in other rows.

The 1968 study with four-wing saltbush was begun 9 July. Rainfall was negligible the first 9 days, therefore the effectiveness of the various mulches was well tested. Less soil moisture was lost under the mulches than in the unmulched rows. Thus, soil moisture remained above the wilting percentage in all mulched rows for 10 days, whereas it dropped below wilting by the 6th day in unmulched rows. Midafternoon temperatures during the 1st week were much lower under straw and WPR:

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[1] Experimental products supplied by Dr. R. L. Ferm, Chevron Research, Richmond, California. Aluminized asphalt, identified as 64R-1101, is a dispersion of a leafing aluminum pigment in an asphalt-volatile hydrocarbon solution; white petroleum resin, 68R-5268, a dispersion of a white pigment in a petroleum derived resin aqueous emulsion. Trade and company names are used for the benefit of the readers, and do not constitute endorsement or preferential treatment by the U.S. Department of Agriculture.

[2] A pigmented latex compound manufactured by Alco Chemical Corporation, Philadelphia, Pennsylvania. Trade and company names are used for the benefit of the reader, and do not constitute endorsement or preferential treatment by the U.S. Department of Agriculture.

	°F
Air (shade)	84
Straw	83
WPR	80
Aluminized asphalt	100
No mulch (control)	103
Soil Gard	108

Seedlings began emerging 6 days after seeding. Stands in rows mulched with straw or WPR were significantly better than those in other rows; these better stands are explained by cooler temperatures, together with higher soil moisture.

In 1969, three mulch studies were conducted: two with fourwing saltbush and one with winterfat. Rates of mulch application per 100 ft of row were:

	Light	Medium	Heavy
Straw (air-dry) in pounds	1.9	3.8	5.8
WPR (not diluted) in gallons	1.0	2.1	3.2
Soil Gard (1:9 dilution) in gallons	1.0	2.1	3.1

The first study with saltbush was conducted during hot, dry, windy weather. Mulches were only partially effective in preventing moisture losses from the top inch of soil, which dried rapidly the 1st week after seeding. The advantages of mulching became evident the 5th and 6th day when more moisture was available to the germinating seed in mulched rows than in unmulched rows. By the 7th day, soil moisture tension exceeded 15 atmospheres in all rows. Nevertheless, a few seedlings emerged. On the 20th day, seedlings per foot numbered 0.6 for WPR, 0.5 for straw, and 0 for Soil Gard and no mulch. High temperatures probably account for the lack of seedlings in rows mulched with Soil Gard. Temperatures in the seed zone at 2:00 p.m. the 6th day--a critical time for the seeds, and seedlings--were as follows:

	°F
Air (shade)	94
Straw	92
WPR	80
No mulch	113
Soil Gard	116

Cooler temperatures, in combination with slightly more moisture available when needed by the germinating seeds, account for the seedlings that emerged in rows mulched with WPR or straw.

The second 1969 study with four-wing saltbush, installed 25 July, was conducted during cool, moist weather. Neither soil temperatures nor moisture tensions reached high levels, but certain mulch treatments resulted in significantly better seedling establishment. The most seedlings became established in rows mulched lightly with straw, as these averages show:

Mulch	Rate	Number per Foot of Row
Straw	Light	5.6 a
	Medium	4.4 ab
	Heavy	3.5 bc
WPR	Light	4.6 ab
	Medium	3.5 bc
	Heavy	2.8 c
Soil Gard	Light	2.9 c
	Medium	1.4 d
	Heavy	1.1 d
No mulch		3.1 c

The poor stands in rows mulched with Soil Gard suggest this dark green elastic coating may impede seedling emergence.

The 1969 mulch study with winterfat was begun 25 August. Emergence and establishment were better where mulch was applied over the seeded rows:

	Number of Plants per Foot of Row		
Mulch	1 Week After Seeding	1 Month After Seeding	1 Year After Seeding
WPR	1.7	2.7	1.9
Straw	1.1	1.8	1.6
No mulch	0.8	1.6	0.8

The greater number of seedlings where WPR was applied is explained by lower temperatures and more moisture. Temperatures under WPR were cooler than under straw. Likewise soil moisture tension usually remained less in rows mulched with WPR.

In 1970, winterfat seeds were planted in moist soil and mulches applied 24 June. Winterfat seedlings began emerging the 2nd day. Seedling stands developed as follows:

	Number of Seedlings per Foot (by days)			
	2	8	12	26
Straw	0.2	0.7	1.1	1.3
WPR	0.5	0.8	0.9	1.0
Soil Gard	0	0.3	0.3	0.3
No mulch	0	0.6	0.5	0.4

Stands were significantly better in rows mulched with straw or WPR than in other rows.

The essentially rainless period of 12 days after seeding provided a good test of the mulches. WPR and straw effectively conserved soil moisture. The germinating seeds and developing seedlings were subjected to less moisture tension in rows mulched with straw or WPR. Differences in temperatures under the three mulches also help explain the differences in seedling emergence. During the first 8 days, soil temperatures under Soil Gard exceeded 100°F every afternoon; the unmulched soil reached 100°F several times. Soil temperatures remained less than 80°F under WPR most days. Temperatures beneath straw likewise were comparatively cool.

The results of these studies at Santa Fe support the basic idea of planting seeds in moist soil and applying a mulch that provides near-optimum temperatures and moisture for germination. In each study, mulching resulted in more moisture for a longer time in the seed zone. As pointed out by McCully and Bowmer (1969), a good mulch properly applied may double the time that moisture in the seed zone is adequate for germination. In some instances mulching may do little more than tip the balance in favor of the germinating seed and developing seedling.

Success of the mulching technique--as used at Santa Fe--is contingent on adequate rainfall. Rain is needed for initial seeding and mulching; and rain is needed later to keep the seedlings alive and growing. Therefore, the seedings were made in summer when rainfall is more dependable. High soil temperatures resulting from high solar radiation in summer were expected to cause problems.

Mulches with reflective properties proved most effective mainly because seeds of four-wing saltbush and winterfat require relatively cool temperatures for germination. Seeds of species with higher temperature requirements might have responded differently to the various mulch treatments. However, investigators have found white- to cream-colored petroleum resin emulsions useful for establishing vegetables in summer when the temperatures of bare soil inhibit germination (Gerard and Chambers, 1967). These investigators reported reflective coatings, though still developmental, show promise because they are easy to apply, suppress evaporation, maintain favorable soil temperatures, and are easily penetrated by seedlings.

Least effective of the mulches tested at Santa Fe was Soil Gard. This material formed a dark green elastic coating that absorbed radiant energy, transmitted it downward, and raised the soil temperatures too high in summer for good germination. This characteristic of certain mulches to raise soil temperatures could be an advantage during cool seasons. For example, the seeds can be placed in moist soil in early spring when soil temperatures are low, and then covered with a dark-colored mulch like Soil Gard.

APPENDIX
(Supplemental Cost Information For Section J)

ESTIMATED COSTS

Chepil et al. (1963)

Crop Residues

	Application Rate (tons)		Cost/Acre[a] (dollars)	
Method of Anchoring	Hay	Straw	Hay	Straw
Disk packer	2.5	3.0	105	120
Cutback asphalt	2.0	2.5	160	220
Asphalt emulsion	2.0	2.5	210	310

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[a] Includes seedbed preparation, seeding, and all mulching costs.

Petroleum Mulches

	Application Rate	Cost/Acre ($)
Cutback asphalt	1/4 gal/yard^2 (1,200 gal/acre)	250
Asphalt emulsion	same	350
Resin-in-water	1/8 gal/yard^2 (600 gal/acre)	225

Other

Fine gravel (1/12 to 1/4 in. diameter) - 20 tons, $55/acre

Medium gravel (1/4 to 1/2 in. diameter) - 50 tons, $200/acre

Coarse gravel (1/2 to 1-1/2 in. diameter) - 100 tons, $375/acre

Bartee (1964) costs of mulching only for establishing plant cover or dams in Texas.

1. Forage sorghum for dead litter - \$34/acre
2. Hay at 2.5 tons/acre - \$175/acre
3. Wood pulp (300 lb/1,000 gal. water) at the rate of 1,000 lb of pulp per acre - \$204/acre

Cannon (1966) cotton planting in Arizona not including application or special equipment costs.

1. 1.25 mil polyethylene, 20 in. wide - \$58/acre
2. Petroleum mulch, 6-in. band at the rate of 100 gal/acre - \$35/acre

Batchelder and Porterfield (1967) cotton planting in Texas Soil Gard (diluted 1:9 in water) applied in 10-in bands at the rate of 1,000 gal/acre - \$55/acre.

Jacoby (1969) coal spoil banks in Wyoming.

	Cost/Acre		
	Material (\$)	Labor (\$)	Total (\$)
Straw	182	91	273
Jute netting	1,307	68	1,375
Jute-straw	1,488	91	1,580

McCully and Bowmer (1969) roadsides in Texas.

Prairie hay at 1.5 tons/acre plus asphalt at 0.05 gal/yard^2 - \$130/acre

K. Representative Soil Test Interpretations for Lime, Nitrogen, Phosphorus, and Potassium[1]

1. Interpretation of pH test - liming: A map (Figure 77) showing the general subsoil pH conditions in Minnesota is furnished. By using Table 26 and the map, the tonnage of lime needed can be readily obtained for the different SMP (Shoemaker, McLean and Pratt test) buffer index values or soil-water pH values. The SMP buffer index is a pH value obtained by use of a buffer solution which takes the reserve soil acidity into account. Reserve acidity is dependent on the amount of organic matter and clay content of each of the soils. The SMP buffer index is not run unless the soil-water pH value is below 6.0. Thus from Table 26, if a soil has a SMP buffer index value of 6.4 the lime requirement would be 5.0 tons/acre for Area 1 (Figure 77) and 2.5 tons/acre for Area 2. As a general practice no lime is applied unless the pH drops below 6.4 in Area 1 and 6. 1 in Area 2.

Table 27 shows the quantity of limestone recommended to change the pH of organic soil (peat and mucks). Lime is not added to organic soils unless the soil-water pH is below 5.5 and then at much lower rates than for mineral soils. The minimum rate of liming for organic soils is 2 tons/acre and the maximum is 5 tons/acre.

Various other liming materials and their equivalent weight or volume as related to ground agricultural limestone are given in Table 28.

2. Interpretation of organic matter test - nitrogen: The organic matter test is expressed as a percent and interpreted as shown in Table 29. The organic matter test is only an indirect indication of the long-term nitrogen supplying power of the soil. Whether nitrogen will be released by organic matter breakdown depends on the moisture status of the soil (high or low moisture--slow release), temperature (high temperature and adequate moisture--rapid release), and type of organic matter.

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[1] Reproduced without change (except for handbook style conformity) from: Foote, L. E., D. L. Kill, and A. H. Bolland, "Erosion Prevention and Turf Establishment Manual," Office of Materials, Construction Division, Minnesota Department of Highways, 43 pages, pp. 19-22 (1970).

Note: Similar soil test interpretations are available from each state soil testing laboratory whose address may be obtained by writing to the respective State Extension Service Director (Section V-A).

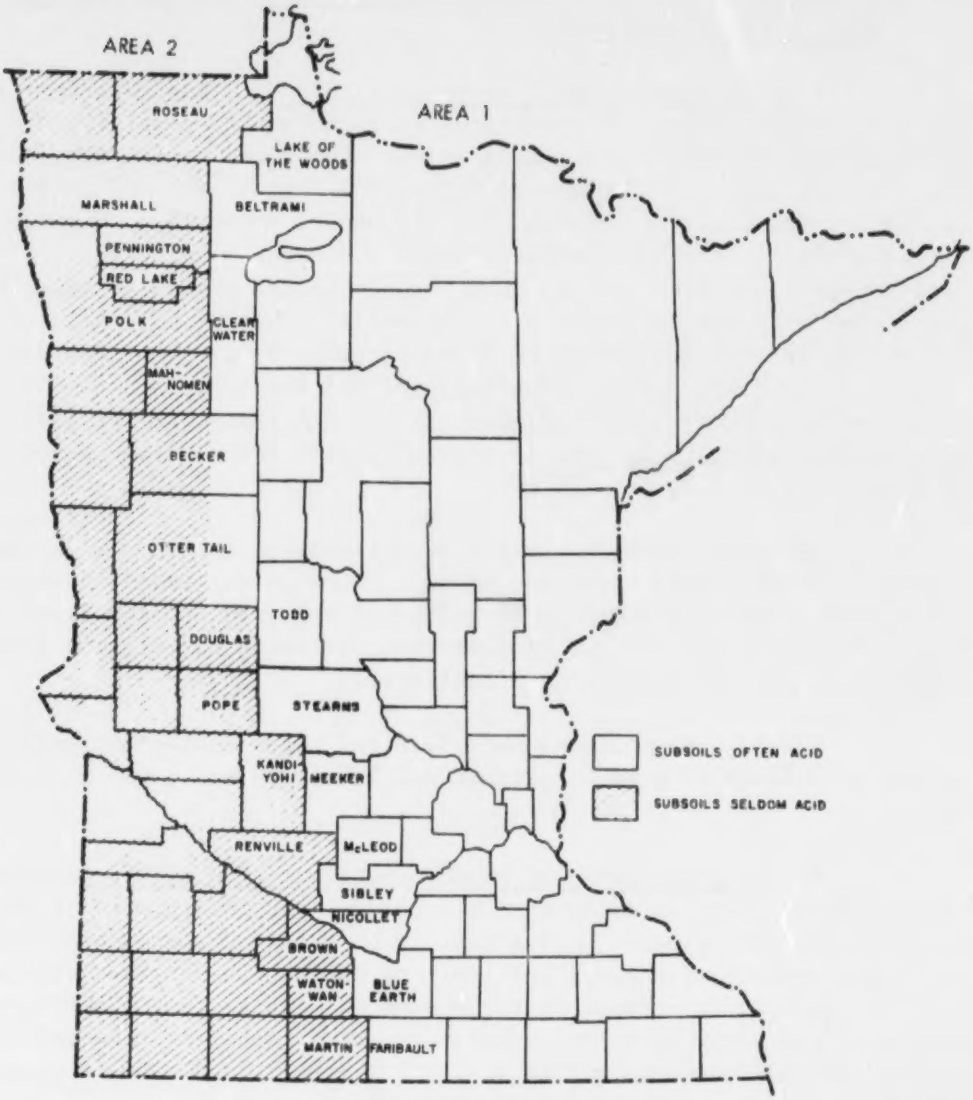
AREA 2
AREA 1
ROSEAU
LAKE OF THE WOODS
MARSHALL
BELTRAMI
PENNINGTON
RED LAKE
POLK
CLEAR WATER
MAH-NOMEN
BECKER
OTTER TAIL
TODD
DOUGLAS
POPE
STEARNS
KANDI-YOHI
MEEKER
RENVILLE
McLEOD
SIBLEY
NICOLLET
BROWN
WATON-WAN
BLUE EARTH
MARTIN
FARIBAULT
SUBSOILS OFTEN ACID
SUBSOILS SELDOM ACID

Figure 77 - Map Used With Table 26 to Determine Lime Need for Mineral Soils

TABLE 26

THE QUANTITY OF GROUND LIMESTONE RECOMMENDED TO CORRECT SOIL ACIDITY AS RELATED TO AREA OF THE STATE AND pH TEST VALUE (MINERAL SOILS ONLY)

SMP Buffer Index	Lime Required (tons/acre) to Raise Soil-Water pH to 6.5	
	Area 1	Area 2
6.8	3.0	2.0
6.7	3.0	2.0
6.6	4.0	2.0
6.5	4.5	2.0
6.4	5.0	2.5
6.3	5.5	2.5
6.2	6.0	3.0
6.1	6.5	3.0
6.0	7.0	3.5
5.9	7.5	3.5
5.8	8.0	4.0
5.7	8.5	4.0
5.6	9.0	4.5

Soil-Water pH		
6.5	0	0
6.4	0	0
6.3	3	0
6.2	3	0
6.1	4	0
6.0	4	2

TABLE 27

THE QUANTITY OF GROUND LIMESTONE RECOMMENDED TO CORRECT SOIL ACIDITY AS RELATED TO THE pH TEST VALUE FOR ORGANIC SOILS (PEATS AND MUCKS)

Soil-Water pH	Lime Required[a/] (tons/acre)
5.4	2
5.3	2
5.2	2
5.1	2
5.0	2
4.9	3
4.8	3
4.7	4
4.6	4
4.5 and lower	5

[a/] Application rates are same for Area 1 and Area 2.

TABLE 28

AMOUNTS OF OTHER LIMING MATERIALS EQUIVALENT TO 1 TON OF GROUND AGRICULTURAL LIMESTONE

Materials	Amounts
Marl	2 yards^3
Carbide refuse lime	2 yards^3
Water-softening process lime	2 yards^3
Papermill refuse lime	2 yards^3
Sugar beet refuse lime	2 yards^3
Blast furnace slag	1 ton
Limestone sludge	1 ton
Eggshells	1 ton
Hydrated lime	1,400 lb

TABLE 29

INTERPRETATION OF SOIL TEST RESULTS

Relative Level	Percent Organic Matter[a] Group I Loamy Sands, Sands	Group II Sandy Loams, Loams, Silt Loams	Group III Clay Loams, Silty Clay Loams, Clays, Sandy Clays	Absorbed Phosphorus[b] (lb/acre (P))	Exchangeable Potassium[c] (lb/acre (K))
Very low	< 0.6	< 1.6	< 2.6	< 6	< 60
Low	0.6-1.5	1.6-3.0	2.6-4.5	6-10	60-90
Medium	1.6-2.5	3.1-4.5	4.6-6.5	11-20	91-220
High	2.6-3.5	4.6-5.5	6.6-7.5	21-30	221-260
Very high	> 3.5	> 5.5	> 7.5	> 30	> 260

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a/ As determined by the wet combustion method using 2 N potassium dichromate and concentrated sulfuric acid.

b/ As determined by using Bray's No. 1 extracting solution.

c/ As determined by using 2 N ammonium acetate extracting solution and the Perkin-Elmer Flame Photometer.

Most roadside seedbed soils on new construction projects are subsoils, mixtures of sub and topsoil or at best subsoils covered with a slope dressing (generally 3 in. of unconsolidated topsoil). Since subsoils usually have a very low organic matter content, the organic matter test is of somewhat limited value.

The amount of nitrogen to apply is determined by the organic matter test, soil texture (more on sandy soils), seed mixture to be used (more with grasses and less when legumes are included), criticalness of the area (the potential for erosion damage) and the socioeconomic factors (more in urban areas--less in rural). Generally 50 to 85 lb of nitrogen per acre are recommended.

The pounds of fertilizer needed per acre to obtain the amount of nitrogen recommended is determined by pounds of N per 100 lb fertilizer times number of hundredweight of fertilizer recommended per acre. Thus 600 lb of 15-10-20/acre equals: 15 lb N/cwt times 6 cwt or 90 lb N/acre. The minimum-maximum amounts used are 24 to 120 lb/acre. The lower range, 24 to 50 lb is used as a starter fertilizer on the organic matter-rich prairie soils of southwestern Minnesota and in the Red River Valley of the north. The higher ranges, 85 to 120 lb are used on sandy soils where no real "topsoil" is present and organic matter is very low or in urban areas of poor subsoils where, due to former buildings, topsoil is scarce and yet a good turf (not coarse legumes or grasses) is desired.

3. Interpretation of phosphorus test: The phosphorus test is expressed as pounds of readily extractable P per acre furrow slice (6-in. depth). It is interpreted as shown in Table 29. However, this interpretation is for agricultural use and assumes former and future applications of phosphorus. This assumption cannot be used in highway work. Since P is readily "fixed" in the soil and not leached out in any quantities, it is possible at construction time to fertilize with P for as many as 10 years. Over time a sufficiently large amount of the applied element will be recovered by the vegetation to justify heavy application rates. Also the P test becomes somewhat inaccurate once a pH of 7.2 or 7.3 is reached and as the pH increases the test becomes more inaccurate in that it overestimates the amount of available P (the reason for this overestimation is unknown).

Phosphorus content in fertilizer is expressed as pounds of P_2O_5 per 100 lb of material. The fertilizer industry is now in the process of changing over to analysis readings based on pounds of actual elemental phosphorus. Until such time as the change is complete, it is necessary to either convert the P test to pounds of P_2O_5 (P x 2.29 = P_2O_5) or to convert the fertilizer P_2O_5 to P (P_2O_5 x 0.44 = P). Since the trend is to use the amount of elemental P it is best to convert the fertilizer, P_2O_5 to pounds of phosphorus.

The minimum-maximum P application range is 15 to 110 lb/acre (34 to 250 lb P_2O_5). Generally, at least 15 lb/acre of P is always recommended as a starter. Under favorable pH conditions (6.2 to 6.8 soil-water solution test) and in a noncritical, better-than-average situation, it is recommended that the P test values from the fertility sample plus application should equal at least 50 lb/acre. If the pH is below 6.2 or between 6.9 and 7.4, the P test value plus application should equal at least 80 lb/acre. If the pH is 7.5 or over, the P test value plus application should equal 110 lb of P per acre. The above guidelines are altered according to the area or site. If the organic matter content is fairly high, topsoil plentiful, not particularly erosive and the soil texture a loam, the application can be somewhat reduced. If subsoils are being used, the soil texture is sandy or claylike and the area has a high erosion potential, the application is increased.

Some authorities might consider these P applications rather high, especially in the case of high P test results (40 to 60 lb) but severe deficiency symptoms can be seen on roadside cuts in such indicator plants as yellow foxtail where fertility tests showed very high amounts of absorbed phosphorus. These P deficiency symptoms have been corrected by P fertilization. Also, as mentioned before, with P there is an opportunity to fertilize on a long-term basis.

4. Interpretation of potassium test: The potassium soil test is based on pounds of exchangeable K per acre (K x 1.20 = K_2O) and the fertilizer analysis is based on pounds of K_2O per 100 lb of material (K_2O x 0.83 = K). The industry is now changing over to pounds of elemental potassium. Potassium is much less important in grass establishment than it is in legume establishment and maintenance. Thus the rate of application depends on both test results and the seed mixture to be used.

The minimum-maximum range of K application is 26 lb/acre (32 lb of K_2O) as a starter under any condition to 230 lb of K per acre (277 lb of K_2O) on soils with a very low K test where legumes are to be seeded. Generally, it is recommended that the K test from the fertility sample plus application equal at least 200 lb of K per acre. If legumes (other than white clover) are included in the seeding mixture as a major component, but are expected to be on a temporary status (6 years or less--alfalfa, red clover, and alsike, are examples) then the K test plus application should equal at least 250 lb. If the legumes included are expected to be on a permanent basis (crownvetch, creeping alfalfa and birdsfoot trefoil) and the major component of the cover, then the K test plus applications should be equal to at least 300 lb/acre. At no time is the K test plus application total allowed to drop below 150 lb/acre.

Potassium is somewhat mobile in the soil and is leached out. But the leaching rate is slow and it is possible to fertilize with K for the future on a short term.

L. Seed and Seeding Data for Grasses, Forbs, Legumes, and Shrubs Adapted to the 17 Western States[1]

TABLE 30

ABBREVIATIONS USED IN SEED AND SEEDING TABLE[1]

State of Adaptation Codes

Arizona	AZ
California	CA
Colorado	CO
Idaho	ID
Kansas	KS
Montana	MO
Nebraska	NB
Nevada	NV
New Mexico	NM
North Dakota	ND
Oklahoma	OK
Oregon	OR
South Dakota	SD
Texas	TX
Utah	UT
Washington	WA
Wyoming	WY

Climatic Zones of Adaptation Codes

Cold - moist winters - CM
(winter moisture equal to or greater than summer)

Cold - dry winter - CD
(winter moisture less than summer)

Warm - moist winters - WM
(winter moisture equal to or greater than summer)

Warm - dry winters - WD
(winter moisture less than summer)

Soils of Adaptation Codes

Sandy - S
Loam - L
Clay - C
Alkali or salty - A
Wet - W

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[1] Reproduced without change (except for handbook style conformity) from: Range Rehabilitation and Equipment Work Conference, Plant Materials Subcommittee, Second Annual Report, Tucson, Arizona, 29 January 1974.

Note: See Section III-K for more details on seed and seeding recommendations.

M. Characteristics and Seeding Recommendations for Grasses and Legumes Adapted to the Midwestern United States[1]

1. Grasses

a. Bentgrass (*Agrostis* spp.): Redtop has the ability to grow under a variety of conditions. It is one of the best grasses for wet land but it also resists drought and grows on soils so low in lime that most other grasses fail. The strength and rhizomatous character of the roots make it useful on banks to prevent erosion. Redtop should be seeded on a compact well-prepared seedbed. It is usually sown broadcast, at the rate of 8 to 15 lb of seed per acre when seeded alone. In a mixture, 2 to 4 lb are commonly used. Fall is considered the best time of year to seed redtop.

The fine bentgrasses, colonial bent, creeping bent, and velvet bent, have been found well adapted for putting greens with other grasses for lawns in much of the northern half of the United States.

b. Bromegrass (*Bromus* spp.): Grasses of the genus Bromus are found mostly in the north temperate zone. About 43 species are native to the United States. Some of our most important forage species as well as our most troublesome weeds belong to this genus.

Smooth brome (*Bromus inermis*) is a long-lived perennial sod grass with heavy creeping rhizomes. It is adapted especially to regions of moderate rainfall and low to moderate summer temperatures. Smooth brome makes its best growth on moist, well-drained clay loam soils of relatively high fertility. Smooth brome is resistant to drought. During the dry periods in its most southwesterly region of adaptation, it becomes dormant until revived by fall moisture.

Several improved varieties and strains of smooth brome are available. Lincoln, Achenbach, Fischer, and Elsberry are varieties certified in several States.

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[1] Reproduced without change (except for handbook style conformity) from: Jackobs, J. A., O. N. Andrews, Jr., C. L. Murdock, and L. E. Foote, "Turf Establishment on Highway Right-of-Way Slopes--A Review," University of Illinois Agronomy Studies Series No. 77, Illinois Cooperative Highway Research Program (1967).

Smooth brome is usually planted in mixtures with legumes. The time and method of seeding will be influenced by the other species in the mixture. Conditions for seeding, seedling emergence, and development are usually best in the spring.

The seeding rate varies depending upon the mixture. In Illinois, 9 to 12 lb/acre of bromegrass and 6 to 8 lb/acre of alfalfa has been found to be satisfactory.

Field bromegrass (Bromus arvensis L.) is a winter annual adapted to the Corn Belt and eastward. Its extensive fibrous root system makes it a good species for holding soil.

The other annual bromegrasses which are not recommended for highway rights-of-way are considered, for the most part, as weedy species. The most common of these is cheat, Bromus tectorum, which occurs in waste places and grain fields.

c. Bluegrass (Poa spp.): The bluegrasses number about 200 species. They ~~are distributed thro~~ughout the world, but mostly in the temperate or cooler regions.

Kentucky bluegrass (Poa pratensis) was introduced from Eurasia. It is common in the northern part of the humid portion of the United States. The latitude of southern Tennessee is its southern limit of satisfactory growth.

Kentucky bluegrass is best adapted to well-drained,highly productive soils of limestone origin. Several varieties are available including Arboretum, Delta, Merion, Newport, Park, and Troy. Merion is probably the most commonly used lawn turf variety in the northern United States.

Kentucky bluegrass is usually seeded in mixtures. It is best to sow in the fall at 4 to 6 lb/acre in mixtures which include other grasses. For turf purposes and rapid establishment, from 20 to more than 100 lb/acre have been used. Prior to seeding, the soil should be limed and fertilized as needed. The seed should be sown on a firm seedbed and covered lightly.

Canada bluegrass (Poa compressa) resembles Kentucky bluegrass somewhat but has a distinct bluegreen foliage. It matures later than Kentucky bluegrass and once grazed or mowed, makes little recovery during the remainder of the season. Its culture and management is similar to that of Kentucky bluegrass.

d. Fescue (Festuca spp.): There are over 100 different species of fescue. They vary from fine to coarse leaved. The growth habit may be creeping or erect. Tall fescue (Festuca arundinacea) and meadow fescue (Festuca elatior) are the two most important species in the United States.

Tall fescue has a wide range of adaptation. It is tolerant of poor drainage, particularly in the winter. With good drainage it has a deep penetrating root system. Tall fescue has been shown to do well on soils ranging in pH from 4.7 to 9.5. It does well on mountain slopes and on low lands. It is a long-lived perennial and has been shown to make growth when the mean weekly temperature is above 40°F. It is not completely dormant when the mean weekly temperature is 34°F. Most of the tall fescue in the United States is either Alta or Kentucky 31. Alta is common in the west and northwest and Kentucky 31 in other parts of the United States.

In general, seedling establishment is slow. Although tall fescue is vigorous after it is established, such vigor is not present in the early stages of growth. As a result of slow initial growth, a clean firm seedbed is most desirable. Seed should not be planted more than 1/4 to 1 in. in depth, depending on soil conditions. Recommended rates of seeding vary from 2 to 16 lb/acre. The higher rates are for well-drained land where a large proportion of other species is desired.

Meadow fescue is a somewhat smaller plant than tall fescue and is not as widely adapted. The chief factor limiting its use in the United States has been its susceptibility to leaf rust. Cultural and management practices for meadow fesuce are similar to those for tall fescue.

There are three major species of fine fescue: sheep fescue, red fescue, and Chewings fescue.

Sheep fescue is adapted to about the same climatic conditions as Kentucky bluegrass. It succeeds better on sandy or gravelly soils than most grasses. The usual rate of seeding is 25 to 30 lb/acre for pure stands.

Red fescue resembles sheep fescue but its leaves are brighter green and it does not grow in tufts but creeps by underground stems. There are two distinct forms, red fescue and Chewings fescue. Red fescue is a creeping grass and Chewings is a tufted grass. Like sheep fescue they are both hardy plants and are especially adapted to shaded dry sites.

e. Orchardgrass (*Dactylis glomerata*): Orchardgrass occurs throughout much of the temperate zone of the northern hemisphere. In North America it is found in the eastern Canadian provinces and in the United States from the Canadian border to the Gulf States, from the Atlantic Coast to the edge of the Great Plains.

Orchardgrass is less winter hardy than smooth brome, timothy, or Kentucky bluegrass. It is adapted farther south than these species and is considered to be more heat tolerant. It starts growth fairly early in spring and continues to grow until freezing weather.

Orchardgrass is less exacting in soil requirements than many of the cultivated grasses. It is able to persist and make growth on relatively thin infertile soils. However, it responds well to high levels of fertility, especially to nitrogen. It does not do very well on highly alkaline soils. Orchardgrass recovers rapidly after grazing or mowing.

Most of the orchardgrass seeded in the United States has been of unimproved domestic origin. Several varieties have been released which show promise. Potomac has probably been used most extensively. The new variety Sterling is expected to find wide usage in the Corn Belt States.

It is best to seed orchardgrass in the early spring. Fall and late summer seedings may be successful if early enough to allow good establishment. The most commonly recommended rates are 3 to 10 lb/acre in association with legumes.

f. Ryegrass (*Lolium* spp.): The name ryegrass applies, in general, to two primary cultivated species of the genus *Lolium*: Italian ryegrass (*Lolium multiflorum*) and perennial ryegrass (*Lolium perenne*).

Italian ryegrass is usually considered an annual. Under some conditions it behaves as a biennial, or even as a short-lived perennial. Perennial ryegrass is quite similar to Italian ryegrass. As its name indicates it is a perennial but is short-lived.

The ryegrasses are not as winter hardy as many grasses including orchardgrass and timothy. They have a wide range of soil adaptation. For most satisfactory growth, however, they require soils of medium to high fertility. They will stand fairly wet soils if there is reasonably good surface drainage. They are not dry land grasses and will not persist in regions with climate extremes of cold, heat or drought.

Ryegrass can be seeded either in the fall or early spring. In sections where winters are severe, spring seedings are used. Where winters are mild early fall seedings are advisable. The seed should be covered, preferably to a depth of approximately 1/2 in. When seeded alone, a seeding rate of 10 to 25 lb/acre is recommended. When seeded in mixtures the rate is usually 4 to 5 lb/acre.

g. Timothy (*Phleum pratense*): Timothy is adapted to cool, humid climates. In the United States most of the timothy is produced in the northern half of the area east of the Missouri River.

Timothy is a bunch grass with erect culms 20 to 40 in. tall. The root system of timothy is relatively shallow and fibrous. It does not spread laterally to form a sod. Although individual shoots are biennial, new shoots develop vegetatively each year and the plant behaves as a perennial.

Timothy may be seeded either in the fall or spring. Seeding rates vary from 2 to 10 lb/acre depending on the species with which it is seeded in mixtures.

h. Reed canarygrass (*Phalaris arundinacea*): Reed canarygrass is adapted to much of the northern half of the United States and southern Canada. When seeded, in most cases, it has been on poorly drained sites subject to flooding and silting. It is a tall coarse, sod forming, cool season perennial.

The natural habitat of reed canarygrass is poorly drained, wet areas, but it has been found to be one of the most drought tolerant cool season grasses when grown on upland soils. However, on upland soils it becomes sod bound and relatively unproductive unless heavily fertilized.

Late summer seeding is usually best, especially on poorly drained areas. Spring seeding is satisfactory when field conditions permit and weeds are not a problem. When good seed is used (80% or higher germination) a seeding rate of 5 to 8 lb/acre is adequate.

i. Zoysia (Zoysia spp.): There are three species of zpysia in the United States, Manilagrass (Zoysia matrella); Japanese lawngrass (Zoysia japonica); and Mascarenegrass (Zoysia tenuifolia). Mascarenegrass is the least hardy and is only grown in California and the south. Japanese lawngrass is the most winter hardy of the three species. It has been grown successfully as far north as Boston. It is tough, harsh and once established very hardy and persistant. Manilagrass is the most widely used of the Zoysias. It has survived the winter as for north as Rhode Island, but its general limit of adaptation is approximately 40 degrees north latitude. It will tolerate some shade, especially in the south.

Seed of the Zoysia grasses is not available in commercial quantities; therefore, vegetative planting is necessary. One square yard of sod is sufficient to sprig plant 750 to 1,000 ft^2 with rows 8 to 10 in. apart and sprigs 3 in. apart in the rows. It is best to establish the Zoysias in the spring as soon as the soil is warm.

One of the principal weaknesses of the Zoysias is their slow rate of establishment. It usually requires at least 2 years to obtain a good cover at the recommended rate of planting. Other grasses may be planted between the rows to afford cover until the Zoysia is established.

2. Legumes: Although it has previously been stated that grasses give better erosion control because of their greater soil aggregating properties, the value of legumes should not be minimized. It is generally accepted that a mixture of grasses and legumes produces more vegetation, partly due to the nitrogen fixation in the nodules of the legumes which also favors the grass in the mixture. Some legumes also have a very deep tap root system which is valuable in holding the soil in place, especially on the steeper slopes.

There are a large number of legumes, many of which have proven valuable in erosion control. The purpose of this review is to list the adaptation of some of the more common ones for the midwestern area.

a. Alfalfa (*Medicago* spp.): Alfalfa is worldwide in distribution. It is well adapted to a wide range of soil and climatic conditions. It has withstood temperatures of -80°F in Alaska, and certain types are grown in Death Valley, California, where maximum temperatures reach 130°F. It is best adapted to deep loam soils with porous subsoils. Good drainage is essential. Alfalfa also requires large amounts of lime and does not do well on soils that are decidedly acid. Alfalfa grows extremely well in dry climates on fertile soil where there is plenty of moisture available, such as under irrigation. Alfalfa is relatively tolerant of alkaline soils but does not do well on highly alkaline soils. It is highly drought resistant but goes into dormancy during dry periods and does not resume growth until moisture is available.

There are two major species of alfalfa, *Medicago sativa* and *Medicago falcata*. *Medicago sativa* is a native of Asia and is purple-flowered and erect. Strains of this species vary in their winter hardiness but as a group tend to be less hardy than *Medicago falcata* which is a native of Siberia. It is a yellow-flowered plant and tends to be decumbent.

There is a third group of alfalfas, the variegated alfalfas, which are believed to have arisen from natural crossing between *Medicago sativa* and *Medicago falcata*. Flower color of this group ranges from purple through blue and yellow to white.

There are many varieties of each type of alfalfa. The common varieties are composed of regional strains with different climatic adaptation. They are usually identified by the name of the State where they originated. All regional strains of common alfalfa are susceptible to bacterial wilt. Buffalo, a variety derived from Kansas common, and the Turkistan alfalfas are resistant to bacterial wilt. The variety Lahontan is of Turkistan origin. Ranger and Vernal are varieties of the variegated types of alfalfa which are also resistant to bacterial wilt.

Alfalfa may be seeded either in later summer or early spring. In regions south of the northern Nebraska border and Illinois Highway 40, late summer seedings are usually best. North of this line, spring seedings are usually more successful. A companion small grain crop sown at about half the usual rate is often used. In most areas from 10 to 20 lb of seed per acre is recommended. The cultipacker seeder, by which the seed is broadcast between two rollers, has given good results. When seed is drilled, they should not be planted too deep; 1/4 to 1/2 in. is preferred depending upon the soil type.

b. Birdsfoot trefoil (*Lotus corniculatus*): The range of birdsfoot trefoil in the United States is from the eastern part of Kansas, Nebraska, and the Dakotas to the Atlantic coast and south to the Ohio River. There is also considerable acreage in California and Oregon. It is not adapted to the low rainfall areas of the west except under irrigation, nor to the humid south.

Birdsfoot trefoil has developed a reputation for the ability to maintain stands on infertile soils. Like other crops, however, it makes best growth on the more productive soils or where highly fertilized. It has been shown to be tolerant to acid soils. Seedlings of birdsfoot trefoil are slow in development and do not compete well with rapidly growing seedlings of other species.

A firm well-prepared seedbed with few competing plants of other species is important in the establishment of birdsfoot trefoil. It should be seeded in the spring or early summer at the rate of 5 to 6 lb/acre. No other legume should be seeded with birdsfoot trefoil.

c. Sweetclover (*Melilotus* spp.): Sweetclover thrives under a wide range of soil and climatic conditions. It has one important restriction in that it cannot tolerate acid soils. It is drought resistant and winter hardy. It is one of the first species to invade and make successful growth on highway cuts where nonacid subsoil is exposed.

The requirements for establishing stands of sweetclover are similar to those for alfalfa. The seeds of sweetclover are "hard" and will not germinate until they have been scarified mechanically or otherwise. If the soil pH is below 6.0, lime should be added well ahead of seeding. Scarified seed is planted at the rate of 10 to 15 lb/acre. Seedings are usually made in the spring with a companion crop.

d. Red clover (*Trifolium pratense*): Red clover is widely adapted throughout the world. It is best adapted where summer temperatures are moderately cool to warm and where adequate moisture is available throughout the growing season.

Fertile well-drained soils of high moisture-holding capacity are best for red clover. It does not have the drought resistance of alfalfa.

It will grow on moderately acid soils, but does best on soils of pH 6.0 or higher. Root-rots and crown-rots are serious diseases of red clover and in the midwest often eliminate stands during the 2nd year. Because of its disease susceptibility, red clover should not be considered a permanent species in this area.

Early spring seedings are usually preferred. It is commonly seeded with a companion crop. It may be broadcast on winter wheat or rye in February or March. Seeding rates are 8 to 10 lb/acre when seeded alone and 4 to 6 lb/acre in mixtures with grass.

e. Lespedeza (Lespedeza spp.): Two annual and one perennial species are the most important lespedezas in the United States. The two annual species are introductions from the Orient, common lespedeza (Lespedeza striata) and Korean lespedeza (Lespedeza stipulacea). The perennial species of most importance is Lespedeza cuneata, sericea lespedeza.

The lespedezas normally are not adapted north of the Ohio and Missouri rivers. However, they have been included in roadside plantings in Illinois with considerable success. They are adapted to a wide range of soil types and fertility levels. Lespedeza will make considerable growth on badly eroded soils and on acid soils low in phosphate. They make better growth, however, on productive well-drained soil. Korean lespedeza is least tolerant of acid soils and most tolerant of alkaline soils.

Lespedeza may be sown from mid-winter to early spring. Broadcasting without covering will generally give satisfactory stands in pastures, meadows and in small grains. When seeded alone 25 to 30 lb of good quality seed per acre should be used.

f. Hairy vetch (Vicia villosa): Hairy vetch is a winter annual with a semivine of growth. It will stand cold temperatures below 0°F and suffers winter damage only when there is severe soil heaving. It can be grown almost anywhere in the United States. It is widely adapted to different soil types and grows well on light sandy soils as well as heavier soils. It is usually seeded in the fall at 20 lb/acre.

g. White clover (*Trifolium repens*): White clover is widely distributed throughout the world. In general white clover is best adapted to the clay and silt soils of the humid section of the United States. There are three general types: (a) large, (b) intermediate, and (c) low growing. Ladino, Pilgrim and Merit are three varieties of the large type. Ladino is the most common variety in the northern United States. The northern common white clover is more winter hardy than Ladino, and it is present with Kentucky bluegrass in most unimproved pastures. One to four pounds of seed are generally sown in the late summer or fall.

h. Alsike clover (*Trifolium hybridum*): Alsike clover is especially adapted to cool climates and wet soils. It will do well on moderately acid to moderately alkaline soils. It is grown extensively in the eastern and northern midwest States.

The time and method of seeding are similar to that for red clover. Four to six pounds of seed per acre are considered as full seeding rates.

i. Crownvetch (*Coronilla varia*): Crownvetch is a perennial legume with creeping stems 2 to 6 ft long. It develops a heavy, branched root system. It reproduces by seeds and spreads vegetatively by fleshy rhizomes. Because of its creeping stems, strong rhizomes, and reclining growth habit it is an ideal plant for erosion control.

Crownvetch appears to be well adapted north of the 35th parallel. It grows best on well-drained soils. While it grows on moderately acid, rather infertile soils, it makes best growth when adequately fertilized and limed.

Crownvetch may be planted as seed or as crowns. When seeded the recommended rate is 5 to 10 lb of well-scarified seed per acre at 1/4 to 1/2 in. Since it is a new species to this country, it is important that seeds be inoculated with the proper strain of Rhizobium. Emergence and seedling growth of crownvetch is very slow.

When crowns are planted, the recommended rate is one crown every 3 ft^2. Closer spacing will result in complete coverage sooner.

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Season Grasses

Species	Native or Introduced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germination	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Bluegrass, big	N	Sherman	917,000	Floret	90	70	21.0	1.0	AZ, CA, CO, ID, MO, NV, NM, ND,	CM	L
Poa ampla									OR, UT, WA, WY		
Bluegrass, camby	N	-------	1,584,000	Floret	84	88	36.4	1.0	CA, CO, ID, MO, NV, ND, OR, SD,	CM	L
Poa cambyi									UT, WA, WY		
Bluegrass, Kentucky	I	Cougar, Fylking Merion, Newport	2,156,000	Floret	90	75	50.0	0.5	all	CD-CM	S-L-W
Poa pratensis		Nugget, Pennstar Windsor								WM-WD	
* Bluegrass, sandberg	N			Floret					CA, CO, ID, MO, NV, ND, OR, SD,		
Poa secunda									UT, WA, WY		
Bluegrass, upland	N	Draylar		Floret					MO, WY	CM	S-L-C
Poa glaucantha											
* Brome, California	N	---------		Floret					CA, OR		
Bromus Carinatus											
* Brome, field	N			Floret					CA		
Bromus arvensis											

1/ Rounded to 1/2 pound units - Shrub species should be seeded at a rate of 1/4 to 1/3 that shown.
2/ Limit to higher elevations or wet areas.
3/ Recommended seeding rate is 1/2 that shown for other species. Buffalo grass should not be broadcast.
4/ With proper scarification.

* Seed is usually in short supply or not available. Named varieties are grown under irrigation and usually available. Species without named varieties are often subject to wild harvest with a variable supply.

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Sea n Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Averag Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Brome, Japanese false Brachypodium pinnatum	I			Floret					CA	WM	L, C
* Brome, meadow Bromus biebersteinii	I	Regar	100,000	Floret	92	85	2.4	10.0	CO, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM, CD	L, [illegible]
* Brome, mountain Bromus marginatus	N	Bromar	90,000	Floret	90	85	1.9	[illegible]	AZ, CA, CO, ID, [illegible]	CM, [illegible]	[illegible]
Brome, smooth Bromus inermis	I	Homesteader, Lancaster, Lincoln, Lyon, [illegible], Manchar, Saratoga, Bay-[illegible], Blair, Carlton	[illegible]	Floret	92	85	[illegible].9	[illegible]	[illegible], WA, WY	CM, CD	S, L, [illegible]
* Fescue, green Festuca viridula	N		479,000	Floret	90	15	11.0	2.0	CO, ID, MO, OR, WA	CM	L
Fescue, hard Festuca ovina var. duriuscula	I	Durar	565,000	Floret	95	85	13.0	2.0	All but KS, OK, TX	CM, CD	L, C

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. [1] 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
* Fescue, Idaho	N		450,000	Floret	90	30	10.3	2.0	CA, CO, ID, MO, NV, OR, UT, WA, WY	CM, CD	L
Festuca idahoensis											
Fescue, red	N	Arctared, Bargena, Boreal, Illahee, Olds, Rainier	479,000	Floret	97	80	11.0	2.0	CA, ID, MO, NV, OR, UT, WA, WY	CM, CD	L, C
Festuca rubra											
* Fescue, sheep	N		565,000	Floret	95	85	13.0	2.0	AZ, CA, CO, ID, MO, NV, ND, OR, SD, UT, WA, WY	CM	L
Festuca ovina											
Fescue, tall	I	Alta, Fown, Fortune, Goar	242,000	Floret	96	86	5.5	4.0	AZ, CA, CO, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM, CD [2]	L, C, A, W
Festuca arundinacea											
* Fescue, thurber's	N			Floret					CO, UT, WY	CM	S, L
Festuca thurberi											
Foxtail, creeping(meadow)	N	Garrison	613,000	Spikelet	90	73	14.1	2.0	All except OK, TX	CM, CD	W
Alopecurus arundinaceus											
Foxtail, meadow	I		900,000	Spikelet	90	80	21.0	1.0	ID, MO, OR	CM, CD [2]	S, L, C, A, W
Alopecurus pratensis											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Season Grasses

Species	Native or Introduced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germination	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. [1] 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
* Indian ricegrass	N		235,000	Floret	95	11	5.4	4.0	All except OK	CM, CD, WD	S, L
Oryzopsis hymenoides											
* Muttongrass	N			Floret				2.0	CA, OR, WA, ID, ND, SD, WY, UT, NV, AZ, NM	CM, WM	L, C
Poa fendleriana											
* Needle and thread	N		115,000	Spikelet	29	13	2.6	8.0	All	CD, WD	S
Stipa comata											
Needlegrass, green	N	Green Stipagrass Lodorm	181,000	Spikelet	97	24	4.2	5.0	AZ, CO, KS, MO, NB, ND, NM, SD, WY	CM, CD	S, L
Stipa viridula											
* Needlegrass, thurber's	N			Spikelet					CA, ID, NV, OR, WA	CM, CD, WD	S, L
Stipa thurberiana											
Oatgrass, tall	N	Tualatin	150,000	Spikelet	84	79	3.4	7.0	AZ, CA, ID, MO, NV, OR, UT, WA, WY	CM, CD [2]	L, W
Arrhenatherum elatius											
Orchardgrass	I	Akaroa, Chinook Latar, Palestine, Pomar, Potomac	540,000	Floret	90	80	12.0	2.0	All	CM, CD [2]	S, L, W
Dactylis glomerata											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	[illegible]
Rescuegrass	N	Cassel, Lamont, Prairie, Texas 46	90,000	Floret	95	85	1.6	14.0	CA, NV, OK, OR, TX	CD	[illegible]
Bromus carthorticus											
Ryegrass, Italian	I	Astor, Gulf Wimmera	241,000	Floret	98	90	5.5	4.0	CA, OR	WM	[illegible]
Lolium multiflorum											
Ryegrass, prennial	I	Linn	247,000	Floret	98	90	5.7	4.0	All	CM, CD	[illegible]
Lolium perenne											
Smilograss	I		884,000		90	80	20.3	1.0	AZ, CA, CO, ID, MO, NV, ND, UT, WY	WM	[illegible]
Oryzopsis miliacea											
Soft chess	I	Blando		Floret					CA, ID, MO, NV, OR, UT, WA	CM, CD, WM	[illegible]
Bromus mollis											
Timothy	I	Climax, Drum-mond, Essex, Swallow	1,300,000	Grain	97	80	30.0	1.0	All	CM, CD, 2/	[illegible]
Phleum pratense											
* Wheatgrass, beardless	N	Whitmar	126,000	Floret	98	75	2.9	7.0	CO, ID, MO, NV, OR, UT, WA, WY	CM	[illegible]
Agropyron inerme											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation 2/	Soils of Adaptation
* Wheatgrass, bluebunch Agropyron spicatum	N		117,000	Floret	96	31	2.7	8.0	CO, ID, MO, NV, ND, OR, UT, WA, WY	CM, CD	L, C
Wheatgrass, crested (desert) Agropyron desertorum	I	Summit Nordan	200,000	Floret	95	85	4.6	5.0	AZ, CO, CA, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM	L, C
Wheatgrass, crested (fairway) Agropyron cristatum	I	Nebr. 3576 Parkway	200,000	Floret	95	85	4.6	4.5	AZ, CA, CO, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM	L, C
Wheatgrass, intermediate Agropyron intermedium	I	Amur, Chief, Greenar, Oahe Tegmar	100,000	Floret	90	85	2.4	10.0	AZ, CA, CO, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM, CD	L
Wheatgrass, pubescent Agropyron trichophorum	I	Green leaf, Luna, Topa,	91,000	Floret	90	85	2.0	12.0	AZ, CA, CO, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM, CD	L, C, A
Wheatgrass, Siberian Agropyron sibericum	I	P-27	250,000	Floret	95	85	5.7	4.0	AZ, CA, CO, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM, CD	L, C
Wheatgrass, slender Agropyron trachycaulum	N	Primar, Revenue	160,000	Floret	90	85	3.7	7.0	AZ, CA, CO, ID, MO, NV, NM, ND, OR, UT, WA, WY	CM	S, L

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Season Grasses

Species	Native or Introduced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germination	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Wheatgrass, streambank	N	[illegible]	170,000	Floret	97	92	5.0	[illegible]	AZ, CO, ID, MT, NM, ND, OR, UT, WA, WY	CM, CD	S, L, [illegible], A
Agropyron riparium											
Wheatgrass, tall	I	[illegible]	[illegible]	Floret	95	85	[illegible]	[illegible]	All	CM, CD 2/	L, [illegible], A, W
Agropyron elongatium											
Wheatgrass, thickspike	N	[illegible]	[illegible]	Floret	95	91	[illegible]	[illegible]	CO, ID, MT, NE, NV, ND, OR, SD, UT, WA, WY	CM, CD	S, L
Agropyron dasystachyum											
Wheatgrass, western	N	[illegible]	110,000	Floret	85	60	[illegible]	[illegible]	All	CM, CD	S, L, C, W
Agropyron smithii											
*Wildrye, basin	N		[illegible]	Floret	78	83	3.8	[illegible]	CA, CO, ID, MT, NV, OR, SD, UT, WA, WY	CM, CD	L, C, A, W
Elymus cinereus											
*Wildrye, blue	N		[illegible]	Floret	80	85	3.1	[illegible]	AZ, CA, CO, ID, MT, NV, NM, OR, SD, UT, WA, WY	CM, CD	S, L, W
Elymus glaucus											
*Wildrye, Canada	N	Mandan	106,000	Floret	80	80	2.4	9.0	All but NV	CM, CD, WD	S, L, C, W
Elymus canadensis											

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SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Cool Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of [illegible]
Wildrye, creeping (beardless) Elymus triticoides	N		51,000	Floret	88	90	[illegible]	20.0	AZ, CA, CO, ID, MO, NV, OR, UT, WA, WY	[illegible]	[illegible]
*Wildrye, mammoth Elymus giganteus	I	Volga		Floret					CA, OR, WA, WY	MW, DW, CW	S, L, C
Wildrye, Russian Elymus junceus	I	Mayak, Sawki Vinall	170,000	Floret	90	90	[illegible]	6.0	AZ, CA, CO, ID, MO, NV, NM, ND, OR, SD, UT, WA, WY	[illegible]	[illegible]
*Veldtgrass, prennial Ehrharta calycina		Mission							CA		

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SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Warm Season Grasses

Species	Native or Introduced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germination	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Bahiagrass	I	Pensicola	166,000	Spikelet	72	70	3.8	5.0	TX	WN, WD	S, L, C, A, W
Paspalum notatum											
Bermuda	I	Coastal, Greenfield, Midland, Midway, Santa Ana	1,360,000	Spikelet	97	86	36.3	1.0	AZ, CA, NM, NV, OK, TX	CD, WD	L, C, A, W
Cynodon dactylon											
Bluestem, big	N	Champ, Kaw, Pawnee	191,000	Grain	90	82	4.4	6.0	CO, KA, [illegible], NE, NM, ND, OK, SD, TX, WY	[illegible]	S, L, W
Andropogon gerardii											
Bluestem, Caucasian	I		860,000	Spikelet	35	27	19.7	1.0	AZ, CA, [illegible], TX		L, C
Andropogon caucasicus											
Bluestem, little	N	Aldous, Blaze, Pastura	[illegible]	Spikelet	50	80	8.7	1.0	CO, KA, [illegible], NE, [illegible], TX, WY	CN, CD, WD	S, L
Andropogon scoparius											
Bluestem, sand	N	Elida, Garden, Woodward	1[illegible]5,000	Spikelet	70	69	2.9	8.0	AZ, CO, KS, MO, NB, [illegible], OK, TX, [illegible], SD	CN, CD, WD	S
Andropogon hallii											
*Bluestem, yellow	I	El Kan, King Ranch Plains	830,000	Spikelet			19.1	1.0	AZ, CA, CO, KS, NV, NM, OK, TX, UT	CD, WD	L
Bothriochloa ischaemum											

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SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Warm Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. [1] 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
* Bristlegrass, plains	N		293,000		70	40	7.0	3.0	AZ, CO, NM, TX	CD, WD	S, L
Setaria macrostachya											
Bristlegrass, yellow	N		1,409,000		60	70	32.0	1.0	AZ, CA, NM, OK, TX	CD, WM, WD	S, L
Setaria lutescens											
Buffalograss [3]	N	Mesa, Sharp's Improved	42,000	Bur	88	45	1.0	10.0	AZ, CO, KA, MO, NB, NM, ND, OK, SD, TX, WY	CD, WD	C, W
Buchloe dactyloides											
Buffelgrass	I	B-15, Higgins	440,000				10.1	2.0	AZ, CA, TX	WD	L
Pennisetum ciliare											
Canarygrass, reed	N	Frontier, Ioreed	550,000	Floret	98	64	12.8	2.0	All but TX	CM, CD [2]	S, L, W
Phalaris arundinacea											
* Cordgrass, prairie	N								All but AZ, CA, NV	CM, CD	W
Spartina pectinata											
* Cottontop, Arizona	N		1,092,000	Spikelet	40	70	25.1	1.0	AZ, TX	WD	S, L
Trichachne Californica											

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SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Warm Season Grasses

Species	Native or Introduced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germination	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
* Curly mesquite	N		269,000	Spikelet	28	19	6.2	4.0	AZ	WM, WD	C
Hilaria belangeri											
Dallisgrass	I		220,000	Spikelet	70	70	5.0	4.0	AZ, CA, OK, TX	WM	L, C, W
Paspalum dilatatum											
* Dropseed, giant	N		1,417,000	Grain	90	51	32.5	1.0	AZ, CO, NM, OK, TX	WM, WD	S
Sporobolus giganteus											
* Dropseed, mesa	N		3,329,000	Grain	98	62	76.4	1.0	NM, AZ, TX	WM, WD	S
Sporobolus flexuosus											
Dropseed, sand			5,298,000	Grain	90	70	123.0	0.5	All	CM, CD, WD	S, L, C
Sporobolus cryptandrus	N										
* Dropseed, spike	N			Grain				1.0	AZ, CA, CO, NM, NV, TX, UT	CD, WM	S
Sporobolus contractus											
* Fescue, Arizona	N	Redondo	550,000	Floret	90	75	12.8	2.0	AZ, CO, NV, NM, TX	CM, CD	L
Fescue arizonica											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Warm Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
* Galleta	N		159,000	Spikelet	69	80	3.7	6.0	AZ, CA, CO, NV, NM, TX, UT	CM, CD	S, L, C, A
Hilaria jamesii											
* Grama, black	N	Sonora Nogal	1,335,000	Spikelet	40	60	31.0	1.0	AZ, CO, NM, OK, TX, UT	CD, WD	S, L
Bouteloua eriopoda											
Grama, blue	N	Lovington	712,000	Spikelet	40	60	16.5	1.5	All but ID, OR, WA	CM, CD, WD	S, L, A
Bouteloua gracilis											
Grama, sideoats	N	Butte, El Reno, Pierre, Premier,	[illegible]	Spikelet	[illegible]	50	[illegible]	7.0	All but ID, OR, WA	CM, CD, WD	S, L
Bouteloua curtipendula		Trailway, Tucson, Uvalde,									
		Vaughn									
Harding grass	I	Wintergreen	[illegible]		95	80	8.1	[illegible]	AZ, CA, NM, OK, OR, TX	WM	L, C
Phalaris tuberosa											
Indiangrass (yellow)	N	Holt, Llano Osage, Oto	175,000	Spikelet	89	53	4.0	6.0	CO, KS, NB, NM, ND, OK, SD, TX,	CM, CD	S, L, W
Sorghastrum nutans									UT, WY		
Kleingrass	I	Selection 75	497,000	Spikelet	97	72	11.4	2.0	AZ, NM, TX	WD	S, L

Panicum coloratum

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SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Warm Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Koleagrass	I	Perla							TX		
Phalaris tuberosa var hirtiglumis											
Lovegrass, atherstone	I			Grain					AZ, CA, NM, TX	WD	S, L, C
Eragrostis atherstonei											
Lovegrass, boer	I	A-84	2,922,000	Grain	90	70	69.0	0.5	AZ, CA, NM, NV, TX	WD	S, L
Eragrostis chloromelas											
Lovegrass, boer (weeping)	I	Catalina	2,922,000	Grain	90	70	69.0	0.5	AZ, CA, NM, NV, TX	WD	S, L
Eragrostis curvula conferta											
Lovegrass, lehmann	I		[illegible],000	Grain	90	60	99.0	0.5	AZ, CA, NM, NV, TX	WD	S, L, C
Eragrostis lehmanniana											
Lovegrass, sand	N	Bend, Nebr-27	1,550,000	Grain	93	75	35.6	1.0	CO, KS, NB, NM, OK, TX	CD, WD	S
Eragrostis trichodes											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Warm Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Lovegrass, weeping	I	Morpa A-67	1,463,000	Grain	90	90	34.0	1.0	AZ, CA, NV, NM, OK, TX	CD, WD	S, L
Eragrostis curvla											
Lovegrass, wilman	I	Poler	1,103,000	Grain	95	52	25.3	1.0	AZ, CA, NM, TX,	WD	S, L
Eragrostis superba											
• Muhly, bush	N		1,500,000	Floret	50	40	18.0	1.0	AZ, NM, TX, UT	WD	S, L
Muhlenbergia porterii											
• Muhly, mountain	N		530,000	Floret	80	30	12.0	2.0	AZ, NM, CO, UT	CM, CD	S, L
Muhlenbergia montana											
Muhly, spike	N	El Vado	1,635,000	Floret	50	30	18.0	1.0	AZ, CO, NM, UT	CM, CD	S, L
Muhlenbergia wrightii											
Panic, blue	I		679,000	Spikelet	70	60	16.0	1.5	TX AZ, CA, NM, OK,	WD 2/	S, L, W
Panicum antidotale											
Panic, harvard	N			Spikelet				8.0	NM, TX	CD, WD	S
Panicum harvardii											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Warm Season Grasses

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Rhodesgrass	I		2,143,000	Grain	60	60	49.2	1.0	CA, TX	WD	L
Chloris gayana											
* Sacaton, (giant)	N		1,758,000	Grain	98	80	40	1.0	AZ, CA, NM, TX	WM, CD	L, C, W, A
Sporobolus wrightii											
* Sacaton, alkali	N		1,750,000	Spikelet grain	98	80	40.0	0.5	All but ND	WM CM, CD., WD	L, C, A, W
Sporobolus airoides											
* Sandreed, prairie	N		274,000				6.3	3.5	CO, ID, MO, NB, ND, SD, WY	CM, CD, WD	S
Calamovilfa longifolia											
* Sprangletop, green	N		538,000		90	80	12.5	2.0	AZ, OK, TX	WM, WD	S, L
Leptochloa dubia											
Switchgrass	N	Blackwell Caddo, Kanlow,	278,000	Spikelet	95	62	6.4	4.0	AZ, CO, ID, KS, NB, NV, NM, ND, OK, SD, TX, UT,	CM, CD	S, L, W
Panicum virgatum		Nebr 28, Pathfinder, Summer									
* Tobosa	N		204,000	Spikelet	*	42	4.7	5.0	AZ, NM, TX	CD, WD	L, C, A, W
Hilaria mutica											
* Vine mesquite	N		143,000	Spikelet	50	30	3.3	7.0	AZ, CO, KS, NM, OK, TX, UT	CD	L, C, W
Panicum obtusum											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Forbs and Legumes

Cool

Species	Native or Introduced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germination	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Alfalfa	I	Ladak, Nomad, Rambler, Ranger	225,000	Seed	99	85	5.2	4.0	All	CD, CM 2/	S, L, C
Medicago sativa		Washoe									
* Alfalfa, sickle			454,000	Seed	97	90	10.4	2.0	CA, CO, ID, MO, NV, OR, UT, WA, WY	CM	L
Medicago falcata											
* Buckwheat, California	N										
Eriogonum fasciculatum											
Burnet, small	I		53,000		90	80	1.2	16.0	AZ, CA, CO, ID, MO, NV, NM, OR, UT, WA, WY	CD, CM 2/	S, L
Sanguisorba minor											
* Chickpea	I			Seed	99	90			CA	CM	L
Cicer arietinum											
Canaryclover, hairy											
Dorycnium hirsutum											
Clover, strawberry	N	Salina	323,000	Seed	97	90	7.4	3.0	All	CM, CD 2/	S, L, W
Tufolium fragiferum											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Forbs and Legumes

Cool

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Clover, white	N		800,000	Seed	99	85	18.0	1.5	All	CM, CD 2/	S, L, W
Trifolium repens											
* Lupine, blue	N				99	90			AZ, CA, CO, ID, MO, NV, NM, ND,		S, L, C
Lupinus angustifolius									OR, WA, WY, UT		
* Medic, black	I		800,000	Seed	95	85	18.0	1.5	All	CM, CD 2/	S, L, W
Medicago lupulina											
Milkvetch, cicer	I	Lutana	122,000	Seed	90	15-50 4/	2.8	8.0	AZ, CA, CO, ID, MO, NV, NM, ND,	CM, CD 2/	S, L, W
Astragalus cicer									OR, UT, WA, WY		
* Penstemon, Rocky Mount-ain	N	Bandera	280,000		93	79	6.4	3.0	AZ, CO, NB, NM, UT, WY	CD, CM 2/	S, L
Penstemon strictus											
Sainfoin	I	Eski	18,000		97	80	0.4	49.0	AZ, CA, CO, ID, MO, NV, NM, ND,	CM, CD 2/	L
Onobrychis viciaefolia									OR, UT, WA, WY		
* Squawcarpet	N								CA, ID, OR, WA	CM	S, L
Ceanothus prostratus											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Forbs and Legumes

Cool

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
Sweetclover	I		262,000	Seed	99	85	6.0	4.0	All	CM, CD 2/	S, L, W
Melilotus spp.											
Trefoil, big	I	Marshfield	828,000	Seed	98	80	23.0	1.0	All	CM, CD 2/	S, L
Lotus uliginosus											
Trefoil, birdsfoot	I	Granger, Tana Cascade Douglas	418,000	Seed	96	90	9.6	3.0	All	CM, CD 2/	S, L, W
Lotus corniculatus											
Trefoil, narrowleaf			383,000	Seed	98	82	8.8	2.5	CA, OR, WA, ID, MD, SD, WY, UT, NV, AZ, NM	CM, WM, CD	L
Lotus tenuis											
Vetch, bramble	I		11,000	Seed	97	90	0.2	100.0	All	CM, WM	L
Vicia enuifolia											
Vetch, crown	I	Emerald, Penn-gift, Vul	119,000	Seed	97	80	2.7	8.0	All	CM, CD	S, L
Coronilla varia											
Vetch, Hungarian	I			Seed					All	CD, CM 2/	C, W
Vicia pannonica											
* Vetch, woollypod	I			Seed							
Vicia dasycarpa											

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Shrubs

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
* Apache, plume	N		420,000		80	45	9.6	2.5	AZ, CA, CO, NV, NM, TX, UT	CM, CD, WM	S, L, C, W
Fallugia paradoxa											
* Bitterbrush, antelope	N		20,000		60	80	0.5	40.0	AZ, CA, CO, ID, MO, NV, NM, OR,	CM, CD 2/	S, L
Purshia tridentata									UT, WA, WY		
* Bush, encelia											
Encelia frutescens											
* Bursage	N										
Franseria spp.											
* Mahogany, mountain	N		40,000		80	40	0.9	21.0	AZ, CA, CO, ID, MO, NV, NM, ND,	CM, CD	S, L
Cercocarpus montanus									OR, SD, UT, WA, WY		
* Sagewort	N		2,576,000				591.7	0.5	AZ, CA, CO, ID, MO, NV, NM, ND,		
Artemesia tridentata vaseyana									OR, SD, UT		
Saltbush, fourwing	N		10,000		80	90	0.7	30.0	AZ, CA, CO, ID, MO, NV, NM, OR,	CM, CD, WD	S, L, C, A
Atriplex cancescens									TX, UT, WA, WY		

SEED AND SEEDING DATA FOR COMMONLY USED SPECIES

Shrubs

Species	Native or Intro-duced	Available Varieties	Seeds per lb.	Seed Unit	Average Purity	Average Germin-ation	Seeds per sq. ft. at 1#/ac.	Recommended lbs/ac. 1/ 20-25 Seeds per sq. ft.	States of Adaptation	Climatic Zones of Adaptation	Soils of Adaptation
* Rabbitbrush, rubber	N		335,000				7.7	3.0	AZ, CA, CO, ID, MO, NV, NM, OR, UT, WA, WY	CM, CD	S, L, C, A, W
Chrysothamnus nauseosus											
* Winterfat	N		150,000		52	80	3.3	7.0	All	CM, CD	S, L
Eurotia lanata											

N. Scientific Names of Plants Mentioned*

Alder, thinleaf	*Alnus tenuifolia*
Alfalfa	*Medicago sativa*
Alkali sacaton	*Sporobolus airoides*
Alsike clover	*Trifolium hybridum*
Annual lespedeza	*Lespedeza striata*
Annual rye	*Secale cereale*
Annual ryegrass	*Lolium species*
Arizona fescuegrass	*Festuca arizonica*
Aspen	*Populus tremuloides*
Aster	*Aster* species
Autumn olive	*Elaeagnus umbellata*
Bahiagrass	*Paspalum notatum*
Balsam poplar	*Populus balsamifera*
Barberry, creeping	*Berberis repens*
Bayberry	*Myrica pennsylvanica*
Beach plum	*Prunus maritima*
Bearberry	*Arctostaphylos urva-ursi*
Bentgrass	*Agrostis* species
Bermuda grass	*Cynodon dactylon*
Big bluegrass	*Poa ampla*
Big bluestem	*Andropogon gerardi*
Big sagebrush	*Artemisia tridentata*
Bindweed	*Convulvulus arvensis*
Birdsfoot trefoil	*Lotus corniculatus*
Bitterbrush, antelope	*Purshia tridentata*
Bittersweet, oriental	*Celastrus orbiculatus*
Black cottonwood	*Populus* species
Black gramagrass	*Bouteloua eriopoda*
Black locust	*Robinia pseudoacacia*
Black spruce	*Picea mariana*
Bladdersenna	*Colutea arborescens*
Blando (soft) bromegrass	*Bromus nollis*
Blue gramagrass	*Bouteloua gracilis*
Box rosemary	*Andremeda polifolia*
Bristly locust	*Robinia fertilis*

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* 1. Fernald, M. L., *Gray's Manual of Botany*, American Book Company 8th Ed., 1,632 pages (1950).

2. "Fertilizer Technology and Use," *Soil Science Society of America*, 2nd Ed., pp. 597-600 (1971).

3. "Grass: The Yearbook of Agriculture, 1948," U.S. Department of Agriculture, pp. 838-854.(1948).

4. Seymour, E. L. D., ed., *The Wise Garden Encyclopedia*, Grosset and Dunlap, 1,380 pages (1970).

Buffalo grass	*Buchloe dactyloides*
Bulbous bluegrass	*Poe bulbosa*
Canada thistle	*Cirsium arvense*
Canada wildrye	*Elymus canadenis*
Caucasian sagebrush	*Artemisia* species
Ceanothus, deerbrush	*Ceanothus integerrimus*
Ceanothus, redstem	*Ceanothus sanquineus*
Ceanothus, snowbrush	*Ceanothus velutinus*
Ceanothus, wedgeleaf	*Ceanothus cuneatus*
Cereal rye	*Secale cereale*
Cheatgrass	*Bromus tectorum*
Cherry, bessey	*Prunus besseyi*
Cherry, bitter	*Prunus emarginata*
Chewings fescuegrass	*Festuca rubra* var. *commutata*
Chinese privet	*Ligustrum* species
Chokecherry, black	*Prunus virginiana melanocarpa*
Cicer milkvetch	*Astragalus* species
Cinquefoil, bush	*Potentilla fruticosa*
Coralberry	*Symphoricarpus orbiculatus*
Corn	*Zea mays*
Crabgrass	*Digitaria* species
Creeping foxtail	*Alopecurus arundinacea*
Creeping juniper	*Juniperus horizontalis*
Creeping red fescuegrass	*Festuca rubra*
Crested wheat grass	*Agropyron cristatum*
Desert wheat grass	*Agropyron desertorum*
Crimson clover	
Crownvetch	*Coronilla varia*
Dodder	*Cuscuta* species
Dogwood, redosier	*Cornus stolonifera*
Douglas-fir	*Pseudotsuga menziesii*
Durar hard fescuegrass	*Festuca ovina* var. *duriuscula*
Elder, blueberry	*Sambucus cerulea*
Eriogonum, sulfur	*Eriogonum umbellatum*
Fairway wheat grass	*Agropyron cristatum* var. *fairway*
Field bromegrass	*Bromus arvensis*
Fine-leafed fescuegrass	*Festuca capillata*
Fireweed	*Epilobium angustifolium*
Forsythia	*Forsythia* species
Four-wing saltbush	*Atriplex canescens*

Foxtail millet	*Setaria* *italica*
Fringed sage	*Artemisia* *frigida*
German millet	*Setaria* *italica*
Goldenrod	*Solidago* species
Greenleaf manzanita	*Arctostaphylos* species
Hairy vetch	*Vicia* *villosa*
Hall's honeysuckle	*Linicera* species
Hard fescuegrass	*Festuca* *ovina* var. *duriuscula*
Honeysuckle, tertarian	*Lonicera* *tartarica*
Incense cedar	*Calocedrus* *decurrens*
Indian ricegrass	*Oryzopsis* *hymenoides*
Indigo bush	*Amorpha* *fruticosa*
Inkberry	*Ilex* *glabra*
Intermediate wheat grass	*Agropyron* *intermedium*
Iris	*Iris* species
Jeffrey pine	*Pinus* *ponderosa* var. *jeffreyi*
Johnsongrass	*Sorghum* *halepense*
Juniper, common	*Juniperus* *communis*
Kentucky bluegrass	*Poa* *pratensis*
Kentucky 31 fescuegrass	*Festuca* *elatior* var. *arundinacea*
Leafy spurge	*Euphorbia* *esula*
Lehmann livegrass	*Eragrostis* *lehmanniana*
Locust, black	*Robinia* *pseudoacacia*
Lodgepole pine	*Pinus* *contorta*
Maiden pink	*Dianthus* *deltoides*
Meadow bromegrass	*Bromus* *erectus*
Meadow foxtail	*Alopecurus* *pratensis*
Millet	*Setaria* species
Moss sandwort	*Arenaria* *verna*
Mountain bromegrass	*Bromus* *carinatus* (*Bromus* *marginatus*)
Mountain mahogany	*Cercocarpus* *montanus*
Mountain muhly	*Muhlenbergia* *montana*
Mountain rye	*Secale* *montanum*
Mountain sage	*Artemisia* species
Mulefat	*Baccharis* species
Multiflora rose	*Rosa* *multiflora*
Needle-and-thread	*Stipa* *comata*
Oats	*Avena* *sativa*
Orchardgrass	*Dactylis* *glomerata*
Paper birch	*Betula* *papyrifera*
Penstemon, bush	*Penstemon* *fruticosus*
Perennial ryegrass	*Lolium* *perenne*
Perennial sow thistle	*Sonchus* *arvensis*
Pinemat manzanita	*Archtostaphylos* species

Pink milfoil	*Achillea millefolium*
Ponderosa pine	*Pinus ponderosa*
Prairie cordgrass	*Spartina pectinata*
Pubescent wheat grass	*Agropyron trichophorum*
Quackgrass	*Agropyron repens*
Quaking aspen	*Populus tremuloides*
Red cedar	*Juniperus virginiana*
Red clover	*Trifolium pratense*
Red fescuegrass	*Festuca rubra*
Red osier dogwood	*Cornus stolonifera*
Redtop	*Agrostis alba*
Reed canarygrass	*Phalaris arundinacea*
Reeves spirea	*Spirea* species
Rose, woods	*Rosa woodsii ultramontana*
Russian knapweed	*Centaurea picris*
Russian wildrye	*Elymus junceus*
Rye, grain	*Secale cereale*
Ryegrass, annual	*Lolium multiflorum*
Sagebrush, big	*Artemisia tridentata*
Sand dropseed	*Sporobolus cryptandrus*
Sedge	*Carex* species
Sericea lespedeza	*Lespedeza sericea* (*Lespedeza cuneata*)
Serviceberry	*Amelanchier* species
Sherman big bluegrass	*Poa ampla*
Shrub lespedeza	*Lespedeza bicolor*
Siberian wheat grass	*Agropyron sibiricum*
Sideoats gramagrass	*Bouteloua curtipendula*
Slender wheat grass	*Agropyron trachycaulum* (*Agropyron pauciflorum*)
Smooth bromegrass	*Bromus inermis*
Snowberry, common	*Symphoricarpos albus*
Snowberry, mountain	*Symphoricarpos occidentalis*
Snow-in-summer	*Cerastium tomentosum*
Sodar streambank wheat grass	*Agropyron riparium*
Sorghum	*Sorghum vulgare*
Soybeams	*Glycine max* (*glycine soja*, *Soja max*)
Spirea	*Spirea* species
Spirea, douglas	*Spirea douglasii roseata*
Squawcarpet	*Ceanothus prostratus*
Sumac, rocky mountain	*Rhus glabra cismontana*
Sweetclover	*Melilotus* species
Sweetclover, white	*Melilotus alba*
Sweetclover, yellow	*Melilotus officinalis*
Sweet fern	*Comptonia asplenifolia*

Switchgrass	*Panicum virgatum*
Tall fescuegrass	*Festuca elatior* var. *arundinacea*
Tall oatgrass	*Arrhenatherum elatius*
Tartarian honeysuckle	*Lonicera tartarica*
Timothy	*Phleum pratense*
Topar pubescent wheat grass	*Agropyron tricophorum*
Tualatin oatgrass	*Arrhenatherum elatius* var. *tualatin*
Vetch, hairy	*Vicia villosa*
Virginia pine	*Pinus virginiana*
Virginsbower, western	*Clematis* species
Weeping lovegrass	*Eragrostis curvula*
Western wheat grass	*Agropyron smithii*
Western yarrow	*Achillea* species
White clover	*Trifolium repens*
White Dutch clover	*Trifolium repens*
White spruce	*Picea glauca*
Whitetop	*Lepidium draba*, *Lepidium repens*, and *Hymenophysa pubescens*
Wichuraiana rose	*Rosa wichuraiana*
Willow	*Salix species*
Willow, scouler	*Salix scouleriana*
Wintergreen	*Gaultheria procumbens*
Winter honeysuckle	*Lonicera* species
Winter ryegrass	*Lolium* species
Wormwood, oldman	*Artemisia abrotanum*
Yarrow	*Achillea millefolium*
Yellow sweetclover	*Melilotus officinalis*

O. Conversion Factors[1/]

Various conversion factors are included in this section for the convenience of the user of this manual in calculationg areas, rates, and volumes. Conversion factors are generally shown for four significant digits suitable for field use with a slide rule. For office calculations, more precise conversion factors of five or more significant digits may be needed in some instances.

UNITS AND EQUIVALENTS

Conversion Factors

To Convert	Into	Multiply By
	A	
acre	hectare or sq hectometer	.4047
	sq feet (sq ft)	43,560.
	sq meters (sq m)	4,047.
	sq miles (sq mi)	1.562×10^{-3}
acre-ft	cu ft	43,560.
	cu yds	1,613.
	gallons (gal)	325,850.
	cu meters (cu m)	1,234.
acre-ft/sq mi	cu ft/acre	68.06

[1/] National Engineering Handbook, Chapter 10, Section 3, Soil converva-tion Service, USDA, April 1971.

To Convert	Into	Multiply By
acre-ft/sq mi	tons/sq mi	See Figure 78 (a and b)
	tons/acre	*
	watershed inches	.01875
	cu meters/sq km (cu m/sq km)	476.3
acre-ft of water	tons	1,359.
acre-inch	acre-ft	.08333
	cu ft	3,630.

C

To Convert	Into	Multiply By
Celsius or Centigrade (C)	Fahrenheit (F)	1.8C + 32
centimeters (cm)	feet (ft)	0.03281
	inches (in.)	0.3937
	meters (m)	0.01
	millimeters (mm)	10.0
centimeters/sec (cps)	ft/min	1.197
cubic centimeters (cc)	cu ft	3.531×10^{-5}
	cu in.	0.06102
	U.S. gallons (U.S. gal)	2.642×10^{-4}
	liters (l)	0.001
	U.S. pints	2.113×10^{-3}
	U.S. quarts	1.057×10^{-3}
cubic feet (cu ft)	cu cms (cc)	28,320.
	cu in.	1,728.
	cu meters (cu m)	0.02832
	cu yards (cu yd)	0.03704
	U.S. gallons	7.481
	liters (l)	28.32

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* After getting tons/sq mi from Figure 78 (a and b), multiply by 1.56×10^{-3} to convert to tons/acre.

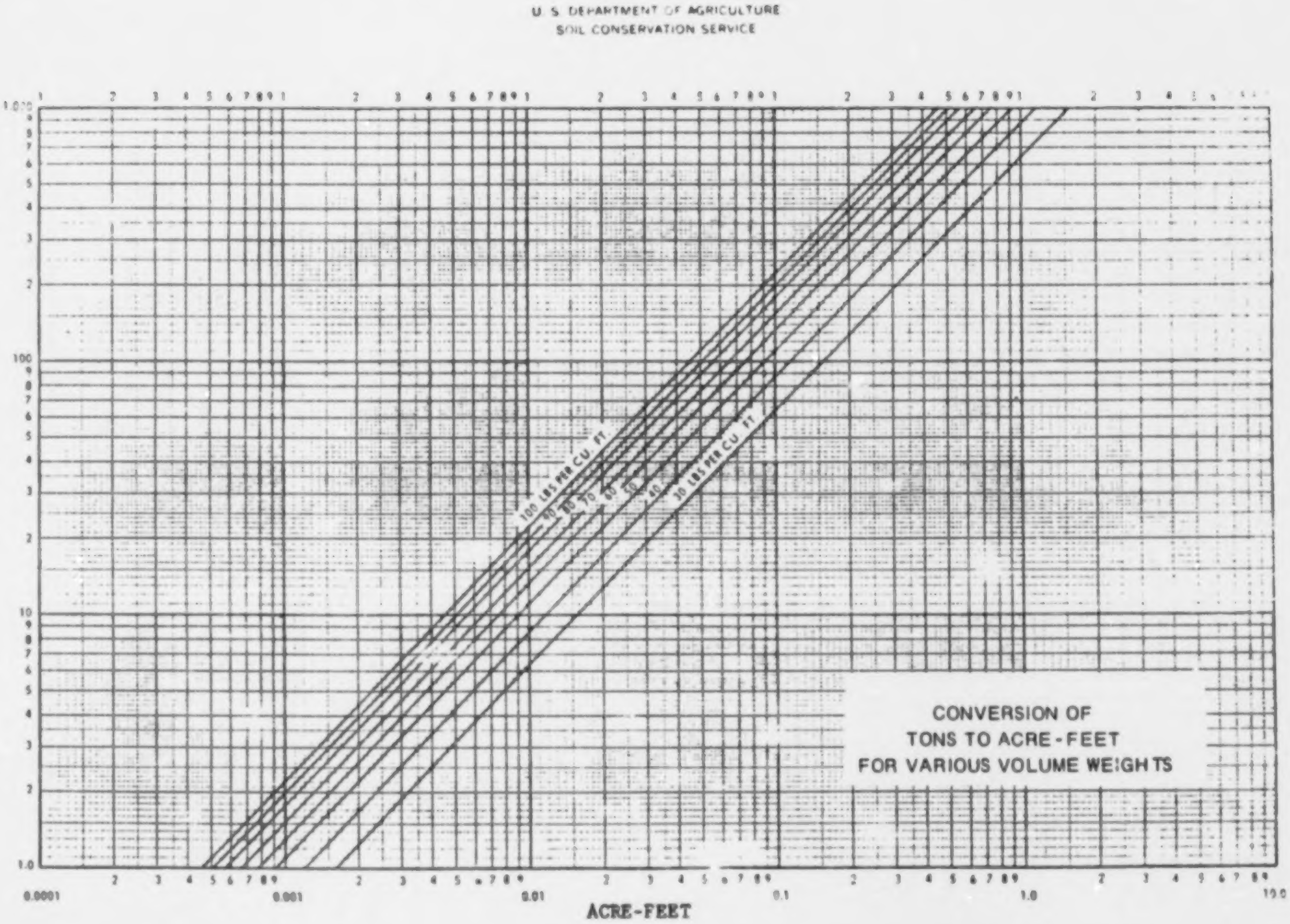

Figure 78a - Conversion of Tons to Acre-Feet for Various Volume Weights

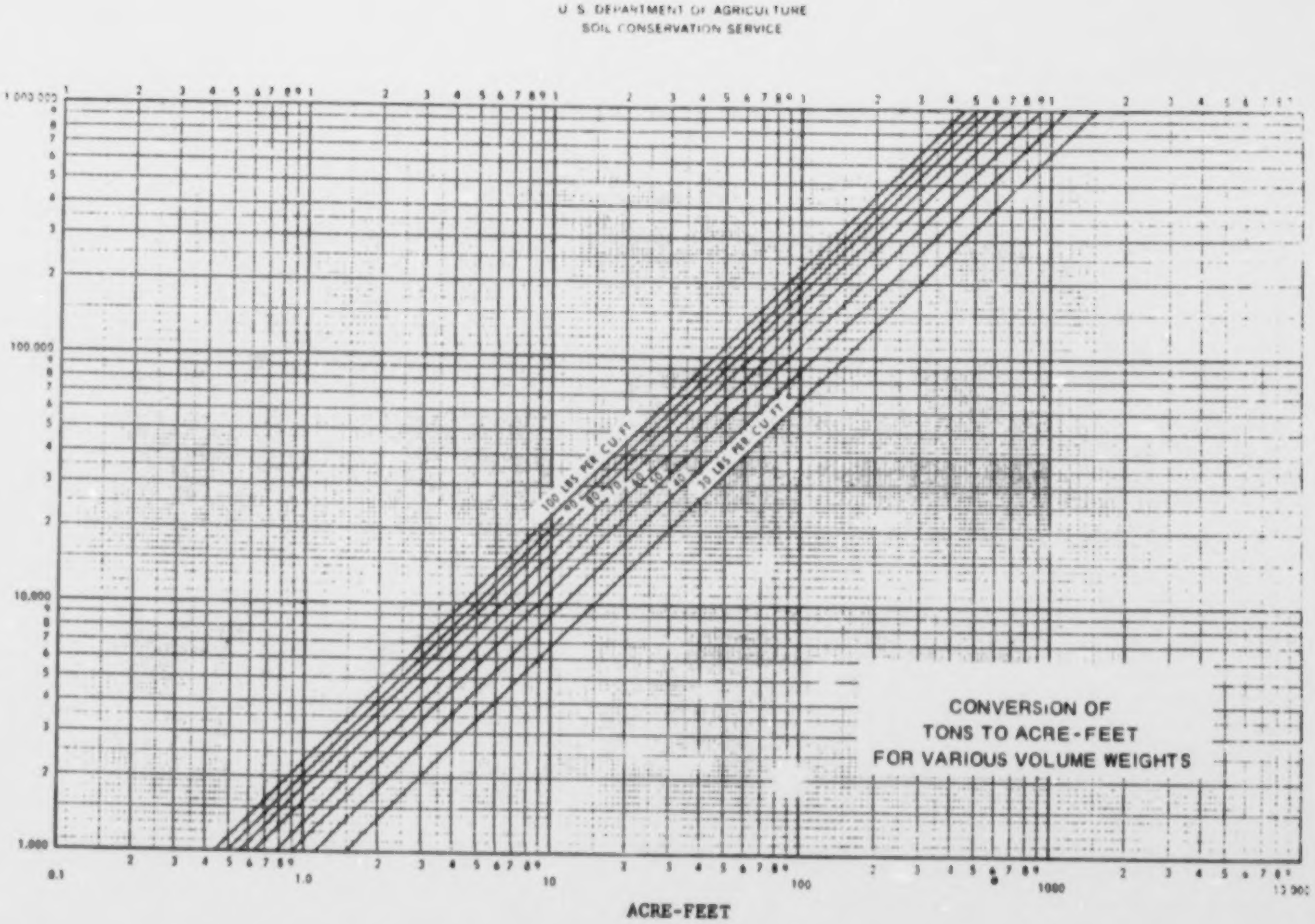

Figure 78b - Conversion of Tons to Acre-Feet for Various Volume Weights

To Convert	Into	Multiply By
cu ft/acre	inches-depth (in.-depth)	2.754×10^{-3}
cubic feet of water	pounds (lbs)	62.43
	kgs/sq cm	0.03048
	kgs/sq meter (kgs/sq m)	304.8
	pounds/sq ft (psf)	62.43
	pounds/sq in. (psi)	0.4335
cubic feet/sec (cfs)	acre-ft per day (ac-ft/d)	1.984
	acre-ft per year (ac-ft/yr)	724.0
	million gal's/day (mgd)	0.6463
	cu m/sec	0.02832
cu ft/sec/sq mi (csm)	liters/sec/sq km (l/sec/sq km)	0.0915
cubic ft/sec (cfs)	gallons/min (gpm)	448.8
cfs-days	cu ft	86,400.
cubic inches (cu in.)	cu cms (cc)	16.39
	cu ft	5.787×10^{-4}
cubic meters (cu m)	cu ft	35.32
	U.S. gallons (U.S. gal)	264.2
	cubic yards (cu yd)	0.7645
cu m/sq km	ac-ft/sq mi	21.0×10^{-4}
cu mi (U.S. statute)	acre-ft	3.379×10^{6}
cubic yards (cu yd)	cu cms (cc)	7.646×10^{5}
	cu ft	27.0
	cu meters (cu m)	0.7646
	U.S. gallons (U.S. gal)	202.0
	acre-ft	6.19×10^{-4}

D

days	seconds (sec)	86,400.
deg F	deg C (Centigrade or Celsius)	(F° - 32).5556

To Convert	Into	Multiply By
	F	
Fahrenheit (F)	Centigrade (C)	$(F^\circ - 32).5556$
fathoms (fthm)	meter (m)	1.829
	feet (ft)	6.000
feet (ft)	centimeters (cm)	30.48
	kilometers (km)	3.048×10^{-4}
	meters (m)	0.3048
	miles (mi)	1.894×10^{-4}
feet/min (fpm)	cms/sec (cps)	0.5080
	feet/sec (fps)	0.01667
	kms/hour (km/hr)	0.01829
	miles/hour (mi/hr)	0.01136
feet/sec (fps)	meters/min (m/min)	18.29
	miles/hour (mph)	0.6818
	km/hour (km/hr)	1.097
	G	
gal (U.S.)	cubic cms (cc)	3,785.0
	cubic feet (cu ft)	0.1337
	cubic inches (cu in.)	231.0
	gallons Br. Imp. (gal Br. Imp.)	0.8327
	liters (l)	3.785
gallons of water	pounds of water	8.3453
gallons/min (gpm)	cu ft/sec (cfs)	2.228×10^{-3}
	liters/sec (l/sec)	0.06308
	cu ft/hr	8.0208
grams (g)	pounds (lbs)	2.205×10^{-3}
gram of water	cu cm of water (cc of wtr)	1.0 (at 4°C)

To Convert	Into	Multiply By
	H	
hectares	acres	2.471
	sq feet (sq ft)	1.076 x 10^5
hours (hr)	days	.04167
	weeks (wk)	5.952 x 10^{-3}
	I	
inches (in.)	centimeters (cm)	2.540
inches (watershed)	cu ft/sec/sq mi (csm)	13.584
inches eroded	tons	1.815 x volume wt (pcf) of upland soil
	K	
kilograms (kg)	pounds, (lb) avoirdupois	2.205
	tons, short (T)	1.102 x 10^{-3}
kilograms/sec(kg/sec)	tons (short)/year (T/yr)	34,786.
kilometers (km)	miles (mi)	0.6214
	L	
liters (l)	cubic cm (cc)	1,000.
	gallons U.S. (gal U.S.)	0.2642
liters/sec/sq km	cubic ft/sec/sq mi (csm)	10.93
	M	
meters (m)	yards (yd)	1.094
	feet (ft)	3.281
	inches (in.)	39.37

To Convert	Into	Multiply By
meters (m)	miles (stat) (mi stat)	6.214×10^{-4}
microns (μ)	meters (m)	1.0×10^{-6}
miles(U.S. stat)(mi)	kilometers (km)	1.609
miles/hour (mph)	feet/sec (fps)	1.467
milligrams/liter(mg/l	parts/million (ppm)	1.000*
milliliters (ml)	liters (l)	0.001
millimeters (mm)	inches (in.)	0.03937
	microns (μ)	1×10^{3}
million gallons/day(mgd)	cu ft/sec (cfs)	1.547
	acre-ft/day	3.069
	cu m/min	2.629
minutes (min)(angles)	degrees (deg)	0.01667
	O	
ounces (oz)	grams (g)	28.35
	pounds (lb)	0.0625
ounces/gallon(U.S.) (oz/gal-U.S.)	gms/liter (gm/l)	7.489
	P	
parts per million (ppm)	milligrams per liter (mg/l)	1.000*
pounds (lb)	grains	7,000.
	grams (g)	453.6
	kilograms (kg)	0.4536
	ounces (oz)	16.00
	tons**	.0005

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* True within 1 percent when the concentration is less than 10,000 ppm.

** Tons means short tons (2000 lbs) unless otherwise indicated, as tons (metric) or tons (long).

To Convert	Into	Multiply By
pounds of water	cubic feet (cu ft)	0.01602
	cubic inches (cu in.)	27.68
	gallons (gal)	0.1198
pounds of water/min	cu ft/sec (cfs)	2.670×10^{-4}
pounds/cu foot(pcf)	grams/cu cm (g/cc)	0.01602
	kgs/cu meter (kg/cu m)	16.02
	pounds/cu in. (pci)	5.787×10^{-4}
pounds/cu in.	gms/cu cm (g/cc)	27.68
pounds/gallon (U.S.)	gms/liter (g/l)	119.8
pounds/cu foot (pcf)	tons/acre-foot(tons/acre-ft)	21.78
pounds/sq foot(psf)	pounds/sq in. (psi)	6.944×10^{-3}

R

To Convert	Into	Multiply By
rods	feet(ft)	16.50
	miles	3.125×10^{-3}

S

To Convert	Into	Multiply By
sq centimeters(sq cm)	square inches (sq in.)	0.1550
square feet (sq ft)	acres	2.296×10^{-5}
square inches(sq in.)	sq cms	6.452
sq kilometers(sq km)	sq miles (sq mi)	0.3861
square meters (sq m)	sq ft	10.76
square miles (sq mi)	acres	640.0
	square feet (sq ft)	27.88×10^{6}
	square kms (sq km)	2.590
	square meters (sq m)	2.590×10^{6}
	square yards (sq yd)	3.098×10^{6}
square yards (sq yd)	square feet (sq ft)	9.000
	square meters (sq m)	0.8361

To Convert	Into	Multiply By
	T	
tons (long)	pounds	2,240.
tons (metric)	kilograms (kg)	1,000.
	tons	1.102
	pounds (lbs)	2,205.
tons (metric)/sq km	tons/sq mi	2.854
tons	kilograms (kgs)	907.2
	pounds (lbs)	2,000.
	tons (long)	0.8929
	tons (metric)	0.9078
tons/sq mi	acre-ft/sq mi	**See Figure 78 (a and b)**
	tons(metric)/sq km	0.350
	tons/acre	1.5625×10^{-3}
tons of water/24 hrs	pounds of water/hour	83.3
	gallons/min (gpm)	0.1664
	cu ft/hr	1.335
tons/acre-ft	pounds/cu ft (pcf)	0.04591
	W	
watershed in.	acre-ft/sq mi	53.33
watershed inches	acre-ft (total)	53.33 x drainage area (in sq mi)
	Y	
years (yr)	seconds (sec)	31.5576×10^{6}

Figure 78 (a and b) are charts for converting various volume weights or weights of sediment per acre-foot to tons. Table 31 below is convenient for the conversion of various volumes of hydraulic or sedimentation data. Table 32 is the Greek alphabet. Table 33 shows map scales and equivalents for use with aerial photographs and USGS quadrangles. Table 34 illustrates conversions in volume weight between pounds per cubic foot and tons per acre-foot. Table 35 converts inches to feet.

TABLE 31

CONVERSION FACTORS FOR HYDRAULIC VOLUMES

Initial Unit	Multiplier to Obtain:				
	Cfs-Days	$Ft^3 \times 10^6$	Gal. $\times 10^6$	Acre-Ft	In/mile^2
Cfs-days	-	0.08640	0.64632	1.9835	0.037190
$Ft^3 \times 10^6$	11.574	-	7.4805	22.957	0.43044
Gal. $\times 10^6$	1.5472	0.13368	-	3.0689	0.05742
Acre-ft	0.50417	0.04356	0.32585	-	0.018750
In/mile^2	26.889	2.3232	17.379	53.33	-

TABLE 32

GREEK ALPHABET

A	α	Alpha	H	η	Eta	N	ν	Nu	T	τ	Tau
B	β	Beta	Θ	θ	Theta	Ξ	ξ	Xi	Υ	υ	Upsilon
Γ	γ	Gamma	I	ι	Iota	O	o	Omicron	Φ	ϕ	Phi
Δ	δ	Delta	K	k	Kappa	Π	π	Pi	X	χ	Chi
E	ε	Epsilon	Λ	λ	Lambda	P	ρ	Rho	Ψ	ψ	Phi
Z	ζ	Zeta	M	μ	Mu	Σ	σ	Sigma	Ω	ω	Omega

Suspended Sediment and Sediment Yield

Conversion of parts per million by weight to sediment yield in tons:

$$\frac{\text{ppm} \times \text{discharge } (\text{ft}^3/\text{period}) \times 62.4}{1{,}000{,}000 \times 2{,}000} = \text{sediment load (tons/period)}$$

TABLE 33

MAP SCALES AND AREA EQUIVALENTS
(Aerial Photographs and USGS Quadrangles)

Fractional Scale	Ft/In	In/Mile[a]	Acres/In^2	In^2/Acre	Mile^2/In^2
1:600	50.00	105.60	0.0574	17.424	0.00009
1:1200	100.00	52.80	0.2296	4.356	0.00036
1:2400	200.00	26.40	0.9183	1.089	0.0014
1:3600	300.00	17.60	2.0661	0.484	0.0032
1:4800	400.00[b]	13.20	3.6731	0.272	0.0057
1:6000	500.00	10.56	5.7392	0.174	0.0090
1:7200	600.00	8.80	8.2645	0.121	0.0129
1:7920	660.00	8.00[b]	10.000	0.100	0.0156
1:9600	800.00	6.60	14.692	0.068	0.0230
1:12000	1,000.00	5.28	22.957	0.044	0.0359
1:15840	1,320.00	4.00[b]	40.000	0.025	0.0625
1:20000[b]	1,666.67	3.168[b]	63.769	0.157	0.0996
1:24000[c]	2,000.00	2.640	91.827	0.011	0.1435
1:31680[c]	2,640.00	2.000	160.000	0.006	0.2500
1:62500[c]	5,208.33	1.014	622.744	0.0016	0.9730
1:63360[c]	5,280.00	1.000	640.00	0.0016	1.0000
1:125000[c]	10,416.67	0.507	2,490.98	0.0004	3.8922
1:126720[c]	10,560.00	0.500	2,560.00	0.0004	4.0000
1:250000[c]	20,933.33	0.253	9,963.91	0.0001	15.5686
1:500000[c]	41,666.67	0.127	39,855.63	0.000025	62.2744
Formulas	$\frac{\text{Scale}}{12}$	$\frac{63,360}{\text{Scale}}$	$\frac{(\text{Scale})^2}{43,560 \times 144}$	$\frac{43,560 \times 144}{(\text{Scale})^2}$	$\frac{(\text{ft/in})^2}{(5,280)}$

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[a] To determine miles per inch, divide scale by 63,360.

[b] Common aerial photograph scales.

[c] Common USGS quadrangle scales.

TABLE 34

VOLUME-WEIGHT CONVERSIONS

1 lb/ft^3 = 0.0005 tons/ft^3; lb/ft^3 x 21.78 = tons/acre-ft

Lb/Ft^3	Tons/Ft^3	Tons/Acre-Ft	Lb/Ft^3	Tons/Ft^3	Tons/Acre-Ft
100	0.0500	2,178.0	79	0.0395	1,720.6
99	0.0495	2,156.2	78	0.0390	1,698.8
98	0.0490	2,134.4	77	0.0385	1,677.1
97	0.0485	2,112.7	76	0.0380	1,655.3
96	0.0480	2,090.9	75	0.0375	1,633.5
95	0.0475	2,069.1	74	0.0370	1,611.7
94	0.0470	2,047.3	73	0.0365	1,589.9
93	0.0765	2,025.5	72	0.0360	1,568.2
92	0.0460	2,003.8	71	0.0355	1,546.4
91	0.0455	1,982.0	70	0.0350	1,524.6
90	0.0450	1,960.2	69	0.0345	1,502.8
89	0.0445	1,938.4	68	0.0340	1,481.0
88	0.0440	1,916.0	67	0.0335	1,459.3
87	0.0435	1,894.9	66	0.0330	1,447.5
86	0.0430	1,873.1	65	0.0325	1,415.7
85	0.0425	1,851.3	64	0.0320	1,393.9
84	0.0420	1,829.5	63	0.0315	1,372.1
83	0.0415	1,807.7	62	0.0310	1,350.4
82	0.0410	1,786.0	61	0.0305	1,328.6
81	0.0405	1,764.2	60	0.0300	1,306.8
80	0.0400	1,742.4			
59	0.0295	1,285.0	39	0.0195	849.4
58	0.0290	1,263.2	38	0.0190	827.6
57	0.0285	1,241.5	37	0.0185	805.9
56	0.0280	1,219.7	36	0.0180	784.1
55	0.0275	1,197.9	35	0.0175	762.3
54	0.0270	1,176.1	34	0.0170	740.5
53	0.0265	1,154.3	33	0.0165	718.7
52	0.0260	1,132.6	32	0.0160	697.0
51	0.0255	1,110.8	31	0.0155	675.2
50	0.0250	1,089.0	30	0.0150	653.4
49	0.0245	1,067.2	29	0.0145	631.6
48	0.0240	1,045.4	28	0.0140	609.8
47	0.0235	1,023.7	27	0.0135	588.0
46	0.0230	1,001.9	26	0.0130	566.3
45	0.0225	980.1	25	0.0125	544.5
44	0.0220	458.3	24	0.0120	522.7
43	0.0215	936.5	23	0.0115	500.9
42	0.0210	914.8	22	0.0110	479.2
41	0.0205	893.0	21	0.0105	457.4
40	0.0200	871.2	20	0.0100	435.6

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1 acre-ft = 43,560 ft^3 = 1,613.33 $yards^3$.

1 day = 24 hr = 1,440 min = 86,400 sec.

TABLE 35

A CONVERSION OF INCHES TO TENTHS OF FEET

1 in. = 0.08 ft
2 in. = 0.07 ft
3 in. = 0.25 ft
4 in. = 0.33 ft
5 in. = 0.42 ft
6 in. = 0.50 ft
7 in. = 0.58 ft
8 in. = 0.67 ft
9 in. = 0.75 ft
10 in. = 0.83 ft
11 in. = 0.92 ft
12 in. = 1.00 ft

Slope Conversions: Grade, Degree, Percent

Grade	Degree (°)	Percent
1/4:1	76	-
1/2:1	64	-
3/4:1	53.5	-
1:1	45	100
1-1/4:1	39	80
1-1/2:1	34	67
1-3/4:1	31	57
2:1	27	50
2-1/4:1	24.5	45
2-1/2:1	22	40
2-3/4:1	20	36
3:1	18.5	33
3-1/4:1	17	31
3-1/2:1	16	29
3-3/4:1	15	27
4:1	14	25

National Bureau of Standards, ASTM Metric Practice Guide, NBS Handbook 102, U.S. Government Printing Office, Washington, D.C. 20402, 46 pages (1967).

The Sillicocks-Miller Company, Conversion Factors: Pamphlet (address: 7 West Parker Avenue, Maplewood, New Jersey 07040).

Zimmerman, O. T., and I. Lavine, Conversion Factors and Tables: Industrial Research Service, Inc., Dover, New Hampshire (1955).

P. Definition of Terms Used in This Manual[1]

AASHO classification (soil engineering): The official classification of soil materials and soil aggregate mixtures for highway construction used by the American Association of State Highway Officials.

Aeration, soil: The process by which air in the soil is replenished by air from the atmosphere. In a well-aerated soil the air in the soil is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen. The rate of aeration depends largely on the volume and continuity of pores in the soil.

Agronomist: A specialist in soil and crop sciences (as affecting the establishment and maintenance of grasses, erosion control, and soil management).

Air porosity: The proportion of the bulk volume of soil that is filled with air at any given time or under a given condition, such as a specified moisture condition. Commonly considered to be the larger pores; that is, those filled with air when the soil is at field capacity. Sometimes called noncapillary pore space when determined as the bulk volume of pores that are unable to hold water when subjected to a tension of 60 cm (23.63 in.) of water.

Alkali soil: (a) A soil with a high degree of alkalinity (pH 8.5 or higher) or with a high exchangeable sodium content (15% or more of the exchange capacity) or both. (b) A soil that contains sufficient alkali (sodium) to interfere with the growth of most crop plants (newer term is sodic soil).

Amendment, soil: An alteration of the properties of a soil, by the addition of substances such as fertilizers, lime, gypsum, and sawdust to the soil for the purpose of making it more suitable for the production of plants.

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[1] "Erosion Control on Highway Construction," National Cooperative Highway Research Program, Synthesis of Highway Practice No. 18, Highway Research Board, Division of Engineering, National Research Council, National Academy of Sciences--National Academy of Engineering, pp. 32-38 (1973). "Glossary of Scientific Terms," Soil Science Society of America, pp. 1-33, July 1973.

Angle of repose: The angle between the horizontal and the maximum slope that an unconsolidated soil material ultimately assumes through natural processes.

Annual plant: A plant that completes its life cycle and dies in 1 year or less.

Apron: A floor or lining to protect a surface from erosion; for example, the pavement below chutes, spillways, culverts, or at the toes of dams.

Aspect (slope): The direction that a slope faces.

Available nutrient: That portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants.

Available water: The portion of water in a soil that can be readily absorbed by plant roots. Considered by most workers to be that water held in the soil against a pressure of up to approximately 15 bars.

Available water-holding capacity (soils): The capacity to store water available for use by plants, usually expressed in linear depths of water per unit depth of soil. Commonly defined as the difference between the percentage of soil water at field capacity and the percentage at the wilting point. This difference in percent multiplied by the bulk density and divided by 100 gives a value in surface inches of water per inch depth of soil.

Bedload: The sediment that moves by sliding, rolling, or bounding on or very near the streambed; sediment moved mainly by gravitational forces, or both, but at velocities less than the surrounding flow.

Bedrock: The solid rock underlying soils and the regolith.

Berm: A raised and elongated area of earth for erosion control intended to direct the flow of water.

Borrow pit: The excavation resulting from the extraction of borrow soil materials.

Broadcast seeding: Scattering seed on the surface of the soil. Contrast with drill seeding, which places the seed in rows in the soil.

Brush matting: (a) A matting of branches placed on badly eroded land to conserve moisture and reduce erosion while trees or other vegetative cover are being established. (b) A matting of mesh wire and brush used to retard streambank erosion.

Bulk density, soil: The mass of dry soil per unit bulk volume. The bulk volume is determined before drying to constant weight at 105°C.

Bunchgrass: A grass that does not have rhizomes or stolons and forms a bunch or tuft.

Calcareous soil: Soil containing sufficient free calcium carbonate or calcium-magnesium carbonate to effervesce visibly when treated with cold 0.1 N hydrochloric acid.

Capillary water: The water held in the "capillary" or small pores of a soil, usually with tension greater than 60 cm (23.63 in.) of water. Much of this water is considered to be readily available to plants.

Cemented: Indurated; having a hard, brittle consistency because the particles are held together by cementing substances such as colloidal organic matter (humus), calcium carbonate, or the oxides of silicon, iron, and aluminum. The hardness and brittleness persist even when wet.

Channel: A natural drainageway that conveys water or a ditch excavated for that purpose.

Check dam: A small dam constructed in a gully or other small watercourse to decrease the streamflow velocity, minimize channel scour, and promote deposition of sediment.

Chiseling: Breaking or loosening the soil, without inversion, with a chisel cultivator or chisel plow.

Clay (soils): (a) A mineral soil separate consisting of particles less than 0.002 mm in equivalent diameter. (b) A soil textural class. (c) (engineering) A fine-grained soil that has a high plasticity index in relation to the liquid limits.

Claypan: A dense, compact layer in the subsoil having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary; formed by downward movement of clay or by synthesis of clay in place during soil formation. Claypans are usually hard when dry, and plastic and sticky when wet. Also, they usually impede the movement of water and air, and the growth of plant roots.

Clearing: The removal of vegetation, structures, or other objects as an item of highway construction.

Climate: The sum total of all atmospheric or meteorological influences, principally temperature, moisture, wind, pressure, and evaporation, which combine to characterize a region and give it individuality by influencing the nature of its land forms, soils, vegetation, and land use.

Clod: A compact, coherent mass of soil ranging in size from 5 to 10 mm (0.2 to 0.4 in.) to as much as 200 to 250 mm (8 to 10 in.); produced artifically, usually by the activity of man by plowing or digging, especially when these operations are performed on clay soils that are either too wet or too dry for normal tillage operations.

Clone: A group of plants derived by asexual reproduction from a single parent plant. Such plants are, therefore, of the same genetic constitution.

Compaction: Increasing soil bulk density and decreasing porosity due to the application of mechanical forces to the soil. Firming is a process of achieving a desirable degree of compaction.

Companion crop: Seeding of a short-life crop with the permanent species to aid in erosion control until the permanent species are established.

Conservation: The protection, improvement, and wise use of natural resources according to principles that will assure their highest economic or social benefits.

Contour: The shape of a land surface as expressed by contour lines.

Contour ditch: A ditch laid out approximately on the contour.

Contour grading plan: A drawing showing an arrangement of contours intended to integrate construction and topography, improve appearance, retard erosion, and improve drainage.

Contour line: (a) An imaginary line on the surface of the earth connecting points of the same elevation. (b) A line drawn on a map connecting points of the same elevation.

Cool-season plant: A plant that makes its major growth during the cool portion of the year, primarily in the spring and fall, but in some localities in the winter.

Corridor: A strip or band of land forming a passageway between two or more points. The width of a corridor may vary from several miles in rural areas to a lesser width in urban areas.

Creep: Slow mass movement of soil and soil material down relatively steep slopes primarily under the influence of gravity, but facilitated by saturation with water, strong winds, and by alternate freezing and thawing.

Critical velocity: The velocity at which a given discharge changes from tranquil to rapid flow.

Cut and fill: A process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

Dam: A barrier to prevent or restrict the flow of water.

Debris: A term applied to the loose material arising from the disintegration of rocks and vegetative material; transportable by streams, ice, or floods.

Debris dam: A barrier built across a stream channel principally to retain rock, sand, gravel, silt, or other material, such as trash or leaves.

Debris guard: A screen or grate at the intake of a channel, drainage, or pump structure for the purpose of stopping debris.

Decumbent: Curved upward from horizontal position.

Deposition: The lying down of material because of reduction of carrying capacity.

Desilting area: An area of grass, shrubs, or other vegetation. used for inducing deposition of silt and other debris from flowing water.

Diversion (channel): (Same as interception ditch.) A ditch constructed across the slope for the purpose of intercepting surface runoff; changing the accustomed course of all or part of a stream.

Drainage: The removal of excess surface water or groundwater from land by means of surface or subsurface drains.

Drill seeding: Planting seed with a drill in relatively narrow rows, generally less than a foot apart. Contrast with broadcast seeding.

Drop-inlet spillway: An overfall structure in which the water drops through a vertical riser connected to a discharge conduit.

Drop structure (drop): A structure for dropping water to a lower level and dissipating its surplus energy; a fall. A drop may be vertical or inclined.

Ecology: The branch of science concerned with the relationship of organisms and their environment.

Ecosystem: A community of organisms and the surroundings in which they live.

Effective precipitation: That portion of total precipitation that becomes available for plant growth. It does not include precipitation lost to deep percolation below the root zone or to surface runoff.

Emergency spillway: A point of discharge used to carry runoff water which exceeds a given design flood resulting from rainfall.

Environment: The sum total of all the external conditions that may act upon an organism or community to influence its development or existence.

Environmental design: A design (of a highway) that includes consideration of the impact of the facility on the community or region based on aesthetic, ecological, cultural, sociological, economic, historical, conservation, and other factors.

Erodible: Susceptible to erosion.

Erosion: Detachment and movement of soil or rock by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion.

Accelerated erosion: Erosion much more rapid than natural, or geological, resulting from the influence of the activities of man or, in some cases, of animals.

Geologic or natural erosion: Natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains, and the building up of flood plains or coastal plains.

Gully erosion: The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 30 to 60 cm (1 to 2 ft) to as much as 170 to 254 cm (75 to 100 ft).

Rill erosion: An erosion process in which numerous small channels of only several centimeters (inches) in depth are formed; occurs mainly on recently cultivated soils.

Sheet erosion: The removal of a fairly uniform layer of soil from the land surface by runoff water.

Splash erosion: The spattering of small soil particles caused by the impact of raindrops on very wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.

Erosive: Refers to wind or water having sufficient velocity to cause erosion. Not to be confused with erodible as a quality of soil.

Exotic: An organism that has been introduced from another continent.

Family, soil: In soil classification one of the categories intermediate between the great soil group and the soil series.

Fertility, soil: The quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants when other growth factors (such as light, moisture, temperature, and the physical condition of the soil) are favorable.

Fertilizer: Any organic or inorganic material of natural or synthetic origin which is added to a soil to supply certain elements essential to the growth of plants.

Fertilizer grade: The guaranteed minimum analysis, in percent, of the major plant nutrient elements contained in a fertilizer material or in a mixed fertilizer. A 20-10-5 fertilizer refers to the percentage of N-P_2O_5-K_2O, respectively.

Fertilizer requirement: The quantity of certain plant nutrient elements needed, in addition to the amount supplied by the soil, to increase plant growth to a designated optimum.

Flume: An open conduit on a prepared grade, trestle, or bridge for the purpose of carrying water across creeks, gullies, ravines, or other obstructions. Sometimes used in reference to calibrated devices used to measure the flow of water in open conduits.

Forb: An herbaceous plant that is not a grass, sedge, or rush.

Grade: (a) The slope of a road, channel, or natural ground. (b) The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction, like paving or laying a conduit. (c) To finish the surface of a canal bed, roadbed, top of embankment, or bottom of excavation.

Graded stream: A stream in which, over a period of years, the slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for transportation of the load (of sediment) supplied from the drainage basin. The graded profile is a slope of transportation. It is a phenomenon in which the element of time has a restricted connotation.

Gradient: The rate of regular or graded ascent or descent.

Grassed waterway: A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses, used to conduct surface water from cropland.

Great soil group: One of the categories in the system of soil classification that has been used in the United States for many years.

Ground cover: Herbaceous vegetation and low-growing woody plants that form an earth cover.

Groundwater: Phreatic water or subsurface water in the zone of saturation.

Growing season: The time during which a plant is periodically producing growth. This period will vary depending on the climate and is usually specified in the contract. It reflects climatic conditions and normal growth periods for the area in which the work is to be accomplished.

Grubbing: The process of removing roots, stumps, and low-growing vegetation.

Habitat: The place where a given organism lives.

Hardpan: A hardened soil layer in the lower A or in the B horizon caused by cementation of soil particles with organic matter or with materials such as silica, sesquioxides, or calcium carbonate. The hardness does not change appreciably with changes in moisture content, and pieces of the hard layer do not slake in water.

Haul road: A temporary road, generally unimproved, used to transport material to and from highway construction, borrow pits, and waste areas.

Heaving: The partial lifting of plants out of the ground, frequently breaking their roots, as a result of freezing and thawing of the surface soil during the winter.

Heavy soil: (Obsolete in scientific use.) A soil with a high content of the fine separates, particularly clay, or one with a high drawbar pull and hence difficult to cultivate.

Herbaceous: Vegetation that is nonwoody.

Herbicides: Chemicals used to control or eradicate vegetation.

Humid: A term applied to regions or climates where moisture, when distributed normally throughout the year, should not be a limiting factor in the production of most crops. The lower limit of precipitation under cool climates may be as little as 51 cm (20 in.) annually. In hot climates it may be as much as 152 cm (60 in.). Natural vegetation is generally a forest.

Humus: That more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues has decomposed, usually amorphous and dark-colored.

Hydraulic grade line: In a closed conduit, a line joining the elevations to which water could stand in risers or vertical pipes connected to the conduit at their lower end and open at their upper end. In open channel flow, the free surface of the water.

Hydraulic gradient: The slope of the hydraulic grade line. The slope of the free surface of water flowing in an open channel.

Impeded drainage: A condition which hinders the movement of water through soils under the influence of gravity.

Incorporate: To mix foreign materials, such as pesticides, fertilizers, or plant residues, into the soil.

Indicator plants: Plants characteristic of specific soil or site conditions.

Indigenous: Produced, growing, or living naturally in a particular region or environment.

Infiltration: The flow of a liquid into a substance through pores or other openings, connoting flow into a soil in contradistinction to "percolation," which connotes flow through a porous substance.

Inlet: The upstream end of any structure through which water may flow.

Inoculation: The process of adding cultures of symbiotic microorganisms to legume seed to enhance atmospheric nitrogen fixation.

Interception channel (diversion channel): A channel excavated at the top of earth cuts, at the foot of slopes, or at other critical places to intercept surface flow; a catch drain.

Interceptor drain: A surface or subsurface drain, or a combination of both, designed and installed to intercept flowing water.

Interdisciplinary approach: An analysis method which involves the application of the training and knowledge of persons from many professions in the assessment of potential impacts of highway projects on the economy, society, and the natural environment.

Internal soil drainage: The downward movement of water through the soil profile. The rate of movement is determined by the texture, structure, and other characteristics of the soil profile and underlying layers and by the height of the water table, either permanent or perched. Relative terms for expressing internal drainage are none, very slow, slow, medium, rapid, and very rapid.

Invert: The lowest part of the internal crosssection of a lined channel or conduit.

Landscape architect: A person trained in the art and science of arranging land and objects upon it for human use and enjoyment such as reducing sedimentation.

Landscape personnel: Persons trained, engaged in, or associated with roadside development. The term as used by highway departments may include agronomists, architects, and others.

Landslide: The failure of a slope in which the movement of the soil mass takes place along interior surfaces of sliding.

Leached soil: A soil from which most of the soluble materials ($CaCO_3$, $MgCO_3$, and more soluble materials) have been removed from the entire profile or have been removed from one part of the profile and have accumulated in a lower part.

Leaching: The removal of materials in solution from the soil.

Legume: A member of the legume or pulse family, Leguminosae. One of the most important and widely distributed plant families. The fruit is a "legume" or pod that opens along two sutures when ripe. Flowers are usually papilionaceous (butterflylike). Leaves are alternate, have stipules,and are usually compound. Includes many valuable food and forage species, such as the peas, beans, peanuts, clovers, alfalfas, sweet clovers, lespedezas, vetches, and kudzu. Practically all legumes are nitrogen-fixing plants.

Loess: Material deposited by wind and consisting of predominantly silt-sized particles.

Mottled zone: A layer that is marked with spots or blotches of different color or shades of color. The pattern of mottling and the size, abundance, and color contrast of the mottles may vary considerably and should be specified in soil description.

Mottling: Spots or blotches of different color or shades of color interspersed with the dominant color.

Median: The portion of a divided highway separating the roads for traffic in opposite directions.

Mulch: Natural or artificial material used to provide more desirable moisture and temperature relationships for plant growth. It is also used to control unwanted vegetation.

Native species: A species that is a part of an area's original fauna or flora.

Outfall: The point where water flows from a conduit, stream, or drain.

Overfall: An abrupt change in stream channel elevation; the part of a dam or weir over which the water flows.

Parent material (soils): The unconsolidated, relatively unweathered mineral or organic matter from which the surface of soils have developed.

Particle-size analysis: Determination of the amounts of different particle sizes in a soil sample, usually by sedimentation, sieving, micrometry, or combinations of these methods.

Ped: A unit of soil structure such as an aggregate, crumb, prism, block, or granule, formed by natural processes (in contrast with a clod, which is formed artificially).

Percolation, soil water: The downward movement of water through soil, especially the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

Perennial plant: A plant that normally lives for 3 or more years.

Permeability: The capacity for transmitting a fluid. It is measured by the rate at which a fluid of standard viscosity can move through material in a given interval of time under a given hydraulic gradient.

Permissible hydraulic velocity: The highest velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scouring of the channel. Syn., safe or noneroding velocity.

pH, soil: A numerical measure of acidity or hydrogen ion activity of a soil. The neutral point is pH 7.0. All pH values below 7.0 are acid and all above 7.0 are alkaline. The negative logarithm of the hydrogen-ion activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator at a specified moisture content or soil-water ratio, and expressed in terms of the pH scale (see reaction, soil).

Plant regeneration: The development of volunteer vegetation from seed or by other natural reproductive processes from plants existing nearby.

Planting season: The period of the year when planting and/or transplanting is considered advisable from the standpoint of successful establishment.

Pressure pan (traffic sole, plow pan, tillage pan, traffic pan, plow sole, compacted layer): An induced subsurface soil horizon or layer having a higher bulk density and lower total porosity than the soil material directly above and below, but similar in particle size analysis and chemical properties. The pan is usually found just below the maximum depth of normal plowing and frequently restricts root development and water movement.

Productivity, soil: The capacity of a soil, in its normal environment, for producing a specified plant or sequence of plants under a specified system of management. The "specified" limitations are necessary since no soil can produce all crops with equal success nor can a single system of management produce the same effect on all soils. Productivity emphasizes the capacity of soil to produce crops and should be expressed in terms of yields.

Profile, soil: A vertical section of the soil through all its horizons and extending into the parent material.

Pure live seed: The product of the percentage of germination plus the hard seed and the percentage of pure seed, divided by 100.

Rainfall intensity: The rate at which rain is falling at any given instant, usually expressed in inches per hour.

Reaction, soil: The degree of acidity or alkalinity of a soil, usually expressed as a pH value. Descriptive terms commonly associated with certain ranges in pH are: extremely acid, less than 4.5; very strongly acid, 4.5 to 5.0; strongly acid, 5.1 to 5.5; moderately acid, 5.6 to 6.0; slightly acid, 6.1 to 6.5; neutral, 6.6 to 7.3; slightly alkaline, 7.4 to 7.8; moderately alkaline, 7.9 to 8.4; strongly alkaline, 8.5 to 9.0; and very strongly alkaline, greater than 9.1 (see pH, soil).

Regolith: The unconsolidated mantle of weathered rock and soil material on the earth's surface; loose earth materials above solid rock. (Approximately equivalent to the term "soil" as used by many engineers and geologists).

Revetment: A facing of stone or other material, either permanent or temporary, placed along the edge of a stream to stabilize the bank and protect it from the erosive action of the stream.

Riprap: Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves); also applied to brush or pole mattresses, or brush and stone, or other similar materials used for soil erosion control.

Rootbed: The soil depth modified by tillage or amendments in which plant roots are or will be growing.

Rounding, slope: The modeling or contouring of roadside slopes to provide a curvilinear transition between several planes; e.g., tops, bottoms, and ends of cuts and fills.

Runoff: That portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, groundwater runoff, or seepage.

Saline soil: (a) A nonalkali soil containing sufficient soluble salts to impair its productivity but not containing excessive exchangeable sodium. This name was formerly applied to any soil containing sufficient soluble salts to interfere with plant growth, commonly greater than 3,000 ppm. (b) A nonsodic soil containing sufficient soluble salt to impair its productivity. The electrical conductivity of the saturation extract is greater than 2 mohms/cm at 25°C.

Saltation: Particle movement in water or wind where particles skid or bounce along the streambed or soil surface.

Scalping: Removal of sod or other vegetation in spots or strips.

Scarify: To abrade, scratch, or modify the surface; for example, to scratch the impervious seed coat of hard seed, or to break the surface of the soil with a narrow-bladed implement.

Scour: The wearing away of terrace or diversion channels or streambeds.

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice.

Sediment load: The quantity of sediment, measured in dry weight or by volume, transported through a stream crosssection in a given time. Sediment load consists of both suspended load and bedload.

Sediment pool: The reservoir space allotted to the accumulation of submerged sediment during the life of the structure.

Sedimentation: The geologic process which includes erosion, transportation, and deposition of solid particles by wind or water.

Seed purity: The percentage of the desired species of seeds in relation to the total quantity, including other species, weed seeds, and foreign matter.

Seedbed: The soil prepared by natural or artificial means to promote the germination of seeds and the growth of seedlings.

Seepage: Water escaping through or emerging from the ground along an extensive line or surface as contrasted with a spring where the water emerges from a localized spot.

Selected earth material: Suitable native material obtained from roadway cuts or borrow areas, or other similar material used for subbase, roadbed material, shoulder surfacing, slope cover, or other specific purposes.

Semiarid: A term applied to regions or climates where moisture is normally greater than under arid conditions but still definitely limiting to the growth of most crops. Dryland farming methods or irrigation generally is required for crop production. The upper limit of average annual precipitation in the cool semiarid regions is as low as 38 cm (15 in.), whereas in tropical regions it is as high as 114 to 127 cm (45 or 50 in.).

Settling basin: An enlargement in the channel of a stream or a dammed area to permit the settling of debris carried in suspension.

Sheet erosion: The removal of a fairly uniform layer of soil from the land surface by runoff water.

Sheet flow: Water, usually storm runoff, flowing in a thin layer over the ground surface. Syn., overland flow.

Side slope: The slope of the sides of a canal, dam, or embankment. It is customary to name the horizontal distance first, as 1.5:1 or, frequently, 1-1/2:1, meaning a horizontal distance of 1.5 ft to 1 ft vertical.

Site: (a) In ecology, an area described or defined by its biotic, climatic, and soil conditions as related to its capacity to produce vegetation. (b) An area sufficiently uniform in biotic, climatic, and soil conditions to produce a particular climax vegetation.

Slope: The degree of deviation of a surface from the horizontal, usually expressed in a ratio, percent, or degrees.

Slope characteristics: Slopes may be characterized as concave (decrease in steepness in lower portion), uniform, or convex (increase in steepness at base). Erosion is strongly affected by shape, ranked in order of increasing erodibility from concave to uniform to convex.

Slope drains: Permanent or temporary devices that are used to carry water down cut or embankment slopes. May be pipe, half sections, paved, or have special plastic lining.

Sod: A closely knit ground cover growth, primarily of grasses.

Sod grasses: Stoloniferous or rhizomatous grasses that form a sod or turf.

Soil conditioner: Any chemical material added to a soil surface for the purpose of improving its physical condition.

Soil conservation: Protection of the soil against physical loss by erosion or against chemical deterioration; that is, excessive loss of fertility by either natural or artificial means.

Soil horizon: A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics, such as color, structure, texture, consistency, kinds and numbers of organisms present, and degree of acidity or alkalinity.

Soil map: A map showing the distribution of soil mapping units in relation to the prominent physical and cultural features of the earth's surface.

Soil management: The combination of all tillage operations, cropping practices, fertilizer, lime, and other treatments applied to the soil for the production of plants.

Soil organic matter: The organic fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic carbon contained in a soil sample passed through a 2-mm sieve.

Soil series: The basic unit of soil classification being a subdivision of a family and consisting of soils which are essentially alike in all major profile characteristics except the texture of the A horizon.

Soil structure: The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Soil survey: A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; the interpretation of soils according to their adaptability for various crops, grasses, and trees; their behavior under use or treatment for plant production or for other purposes.

Soil texture: Soil textural class names of soils are based upon the relative percentages of sand, silt, and clay (see Figure 79).

Spoilbank (waste): A pile of soil, subsoil, rock, or other material excavated from a drainage ditch, pond, or other cut.

Sprigging: The planting of a portion of the stem and/or root of grass.

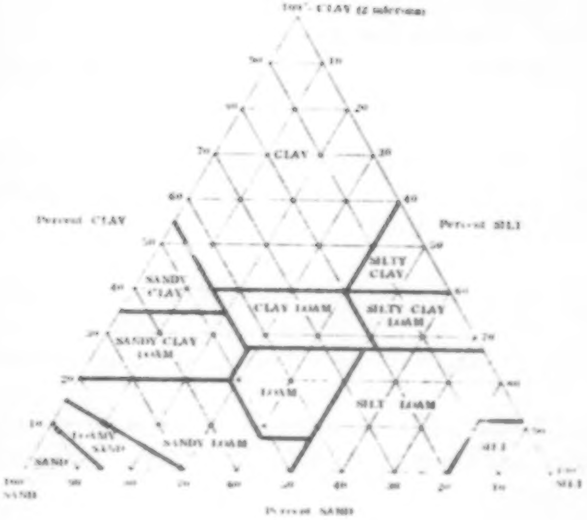
100% CLAY (2 microns)
Percent CLAY
Percent SILT
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SILT LOAM
LOAMY SAND
SANDY LOAM
SAND
SILT
90
80
70
60
50
40
30
20
10
100 SAND
100 SILT
Percent SAND

Figure 79 - Graph Showing the Percentages of Sand, Silt, and Clay in the Soil Textural Classes

Stilling basin: An open structure or excavation at the foot of an overfall, chute, drop, or spillway to reduce the energy of the descending stream.

Subsoil: The stratum of material beneath the surface soil.

Surface soil: The uppermost part of the soil, ordinarily moved in tillage, or its equivalent in uncultivated soils, ranging in depth from about 13 to 20 cm (5 to 8 in.). Frequently designated as the plow layer, the Ap layer, or the Ap horizon.

Terrace (agriculture): An embankment or combination of an embankment and channel constructed across a slope to control erosion by diverting runoff instead of permitting it to flow uninterrupted down the slope.

Tillage: The mechanical manipulation of soil for any purpose; but in agriculture it is usually restricted to the modifying of soil conditions for crop production.

Tillage equipment (tools): Field tools and machinery which are designed to lift, invert, stir, or pack soil, reduce size of clods and uproot weeds; i.e., plows, harrows, disks, and cultivators.

Tilth: The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration.

Toe (engineering): The lower edge or edges of a slope.

Tolerant: Capable of growth and survival under competitive growing conditions.

Topography (lay-of-the-land): The configuration of the earth's surface, including the shape and position of its natural and man-made features.

Topsoil: The upper layer of soil containing organic matter and usually suited for plant survival and growth. On a construction site the topsoil is commonly saved for topsoiling.

Transpiration: The process by which water vapor is released to the atmosphere by the foliage or other parts of a living plant.

Trap efficiency: A measurement of the effectiveness of a basin to trap sediment.

Underground (underflow) runoff (seepage): Water flowing toward or into stream channels from adjacent ground.

Urbanized area: An area identified by the U.S. Bureau of the Census as having a population over 50,000 or by the Office of Management and Budget as a standard metropolitan statistical area. Small urban areas are those areas which have a population of 5,000 to 50,000.

Vegetation: Plant life collectively.

Warm-season plant: A plant that completes most of its growth during the warm portion of the year, generally late spring and summer.

Waste (construction): Excess earth, rock, vegetation, or other materials resulting from highway construction.

Water control (soil and water conservation): The physical control of water by such measures as conservation practices on the land, channel improvements, and installation of structures for water retardation.

Water table: The upper surface of groundwater or that level below which the soil is saturated with water.

Water table, perched: The water table of a saturated layer of soil which is separated from an underlying saturated layer by an unsaturated layer.

Watershed area (calchment): All areas within the confines of a drainage divide.

Weathering: All physical, chemical, and biological changes produced in rocks, at or near the earth's surface.

Q. General References

Alban, E. K., and K. W. Reisch, "A Study of Roadside Maintenance and Landscape Plant Development," Ohio State University, Department of Horticulture, Research Project 285, Ohio-DOT-13-173, 65 pages, June 1973.

Aldon, E. F., "Revegetating Disturbed Areas in the Semiarid Southwest," Journal of Soil and Water Conservation, pp. 223-225, September-October 1973.

Anderson, H. W., "Sediment Deposition in Reservoirs Associated with Rural Roads, Forest Fires, and Catchment Atributes," Proceedings of the International Symposium on Effects of Man on Erosion and Sedimentation, International Association of Hydrology Science, pp. 88-95 (1974).

Austin, M. E., "Land Resource Regions and Major Land Resource Areas of the U.S. (exclusive of Alaska and Hawaii)," USDA, Soil Conservation Service, Agriculture Handbook 296, 82 pages (1965).

Beard, J. B., J. A. Fischer, J. E. Kaufmann, and D. P. Martin, "Improved Establishment and Maintenance of Roadside Vegetation in Michigan," Michigan State University, 66 pages (1971).

Becker, B. C., and T. R. Mills, "Guidelines for Erosion and Sediment Control Planning and Implementation," Project 15030 FMZ, EPA-R2-72-015, Hittman Associates, Inc., and U.S. Environmental Protection Agency, 228 pages, August 1972.

Bieber, G. L., C. Y. Ward, and S. D. Atwell, "Establishment of Vegetation," Volume 1--Agronomy, Mississippi State University, Mississippi Highway Department and U.S. Department of Transporation--Federal Highway Administration, 145 pages (1968).

Blaser, R. E., "Effects of Deicing Salts on Water Quality and Biota," Virginia Polytechnic Institute, Project 16-1, Report No. 91.

Butler, B. J., "Equipment and Techniques for Roadside Spraying," Illinois Cooperative Highway Research Program Series No. 67, Project 1HR-58, University of Illinois, State of Illinois Division of Highways, and U.S. Department of Commerce, Bureau of Public Roads, 36 pages (1967).

Carpenter, P. L., "Herbicide Studies in Landscape Plantings," Purdue University and Indiana Highway Commission, No. 5, 13 pages (1972).

Chan, F. J., R. W. Harris, A. T. Leiser, J. L. Paul, and R. E. Fissell, "Direct Seeding of Woody Landscape Plants," Research Project HPR-PR-1(6) F0502, RTA 13945-13069 UCD, State of California Transportation Agency, Department of Public Works, Division of Highways, University of California in cooperation with the U.S. Department of Transporation, Federal Highway Administration, 81 pages (1971).

Clyde, C. G., E. C. Israelson, and P. E. Packer, "Erosion Control on Highway Construction," Utah State University, Project 16-3, Fiscal Year 1973.

"Comparative Costs of Erosion and Sediment Control-Construction Activities," EPA-430/9-73-016, U.S. Environmental Protection Agency (Robert E. Thronson, Project Officer), 205 pages, July 1973.

"Construction Guidelines for Temporary Erosion Controls," State of New York, Department of Transportation, Albany, 24 pages, April 1974.

Creech, J., Director, U.S. National Arboretum, 24 and R. Streets, N.E., Washington, D.C. 20002.

Donahue, R. L., J. C. Shickluna, and L. S. Robertson, Soils: An Introduction to Soils and Plant Growth, Prentice-Hall, Inc., 587 pages (1971).

Dunkley, C. L., "Suggestions for Temporary Erosion and Siltation Control Measures," sponsored by U.S. Department of Transporation, Federal Highway Administration, 40 pages, February 1973.

"Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization," Project No. C-1677, Contract No. 14-31-0001-3392, Dow Chemical Company, Midland, Michigan, 181 pages (1972).

"Environmental Do's and Don'ts on Construction Sites," USDA, Soil Conservation Service, Miscellaneous Publication No. 1291, 32 pages (1974).

Environmental Guidebook for Construction, Bureau of Reclamation, U.S. Department of the Interior, in press (1974).

"Environmental Protection and Pollution Research Groups Related to Horticulture in the United States and Canada," American Society for Horticultural Sciences, Box 109, St. Joseph, Michigan 49085, 66 pages (1973).

"Erosion Control on Highway Construction," National Cooperative Highway Research Program Synthesis of Highway Practice 18, Highway Research Board, Division of Engineering, National Academy of Sciences-National Academy of Engineering, 52 pages (1973).

"Erosion and Sediment Control on Urban and Construction Sites--An Annotated Bibliography," American Society of Agricultural Engineers, 13 pages (1972).

Feyerherm, A. M., L. D. Bark, and W. C. Burrows, "Probabilities of Sequences of Wet and Dry Days in Alaska," North Central Regional Research Publication No. 161 and Kansas State University Technical Bulletin 139C, 55 pages (undated).

Field, R., E. J. Struzeski, Jr., H. E. Masters, and A. N. Tafuri, "Water Pollution and Associated Effects from Street Salting," EPA-R2-73-257, 48 pages, May 1973.

"Field Manual of Soil Engineering," 5th ed., Michigan Department of State Highways, Report No. 1583, 474 pages (1970).

Franks, K. N., "Establishment and Maintenance of Roadside Plantings and Turf," Research Report 360, Department of Highways, Commonwealth of Kentucky in cooperation with the U.S. Department of Transporation, Federal Highway Administration, 151 pages (1973).

Gallup, R. M., "Roadside Slope Revegetation" (Past and Current Practice on the National Forests), Equipment Development and Test Report 7700-8, USDA Forest Service, Equipment Development Center, San Dimas, California, 37 pages, June 1974.

"Glossary of Geology and Related Science," 2nd ed., American Geological Institute, Washington, D.C., 397 pages (1960).

The Goal, Objectives and Principles of Erosion and Sediment Control Workbook," Hittman Associates, Inc., Columbia, Maryland, reprinted by the Michigan Water Resources Commission for Further Implementation of Act 347 P.A. of 1972, published in 1973.

Goss, R. L., R. M. Blanchard, and W. R. Melton, "The Establishment of Vegetation on Nontopsoiled Highway Slopes in Washington," Washington State University, Washington State Highway Commission, and U.S. Department of Transportation, Federal Highway Administration, 29 pages (1970).

Grant, K. E., "Guidelines for Minimizing Soil Erosion and Water and Air Pollution During Construction," Engineering Memorandum-66 (Rev. 1), USDA Soil Conservation Service, Washington, D.C., 21 June 1973.

"Grass Varieties in the U.S.," by A. A. Hanson, USDA Agriculture Handbook No. 170, 124 pages (1972).

Gray's Manual of Botany, 8th ed., American Book Company, 1632 pages (1950).

Green, J. T., Jr., R. E. Blaser, and H. D. Perry, "Establishing Persistent Vegetation on Cuts and Fills Along West Virginia Highways," Project No. 26, Phase II, Virginia Polytechnic Institute and State University, West Virginia Department of Highways, and U.S. Department of Transporation, Federal Highway Administration, 92 pages (1973).

"Guidelines for Erosion and Sediment Control Planning and Implementation," Department of Water Resources, State of Maryland and Hittman Associates, Inc., U.S. Environmental Protection Agency, EPA-R2-72-015, 228 pages, August 1972.

Guy, H. P., and E. Jones, Jr., "Urban Sedimentation - In Perspective," *Journal of the Hydraulics Division*, *Proceedings of the American Society of Civil Engineers*, HY 12, pp. 2099-2016, December 1972.

Hanson, A. A., and F. V. Juska, editors, "Turfgrass Science," *American Society of Agronomy*, 715 pages (1969).

Haynes, J. N. J. H. Tinga, and F. B. Perry, Jr., "A Systematic Cataloging and Evaluation of Plant Materials for Highway Use in Georgia," Research Project 6606, University of Georgia, State Highway Department of Georgia, and U.S. Department of Transportation, Federal Highway Administration, 281 pages (1972).

Helmick, O. L., "Grass in Right on Rights-of-Way," *Soil Conservation*, **39**(5):6-7, December 1973.

Hodder, R. L., "Revegetation Methods and Criteria for Bare Areas Following Highway Construction," Montana State University, Montana Highway Commission, U.S. Department of Transportation, Federal Highway Administration, 97 pages (1970).

Huffine, W. W., and L. W. Reed, "Continued Evaluation of Roadside Development and Erosion Control Experiments," Parts I, II, and III, No. Oklahoma HPR-1(5), Research Project No. 68-07-3, Oklahoma State University, Oklahoma Department of Highways, and U.S. Department of Transportation, Federal Highway Administration, 74 pages (undated).

Huffine, W. W., L. W. Reed, and G. W. Roach, "Roadside Development and Erosion Control," Oklahoma Project 63-03-3, Oklahoma State University, Oklahoma Department of Highways, and the U.S. Department of Transportation, Federal Highway Administration, 20 pages (undated).

Hamilton, D. F., R. E. McNiel, and P. L. Carpenter, "Establishing Roadside Slopes by Direct Seeding with Legumes and Woody Ornamentals and by Seedlings of Ornamental Plants," Project No. C-36-48C, No. 11, Purdue University, Indiana State Highway Commission, and the U.S. Department of Transportation, Federal Highway Administration, 28 pages (1972).

Hamilton, D. F., R. E. McNiel, and P. L. Carpenter, "Root Cuttings for Roadside Slope Stabilization," Purdue University, Indiana State Highway Commission, and U.S. Department of Transportation, Federal Highway Administration, No. 9, 25 pages (1972).

"Implementation Package for Roadside Vegetation Study," Mississippi State Highway Department, Research and Development Division in cooperation with Federal Highway Administration, U.S. Department of Transportation, 35 pages, October 1973.

Jamison, V. C., "Resistance to Wetting in the Surface of Sandy Soils Under Citrus Trees in Central Florida," *Soil Science Society of America Proceedings*, 11:103-109.

Jagschitz, J. A., and R. S. Bell, "American Beachgrass: Establishment, Fertilization, Seeding," University of Rhode Island, Bulletin 383, 43 pages (1966).

Jagschitz, J. A., and R. S. Bell, "Restoration and Retention of Coastal Dunes with Fences and Vegetation," University of Rhode Island, Bulletin 382, 43 pages (1966).

Johnson, A. E., et al., "Development of Ground Covers for Highway Slopes," Investigation No. 615, Technical Bulletin 282, University of Minnesota, 55 pages (1971).

Küchler, A. W., "Potential Natural Vegetation of the Conterminous United States," Map on scale of 1:3, 168,000, Special Publication No. 36, U.S. Geological Survey (1961).

"Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants, Agriculture/Silviculture/Mining/Construction," U.S. Environmental Protection Agency, 259 pages (1973).

Mitchell, E., "Soils That are Hard to Wet Can be Chemically Treated," In: Farm Supplier, pp. 34-38, January 1972.

Mitchell, W. W., Head Agronomist, Agriculture Experimental Station, University of Alaska, Box AE, Palmer, Alaska 99645.

Morre, D. J., and D. A. Werderitsch, "Chemical Weed Control," Joint Highway Research Project, Purdue University and Indiana State Highway Commission, No. 24, 102 pages (1972).

Murphy, L. M., L. E. Foote, and R. B. Doerr, "Landscape Planting Species Survival," Investigation No. 628, Minnesota Department of Highways, Department of Transportation, Federal Highway Administration, and Minnesota Local Road Research Board, 69 pages (1971).

McCully, W. G., and J. L. Stubbendieck, "Establishment and Management of Roadside Vegetation, 1971," Research Report 142-3, Research Study 2-18-69-142, Texas Highway Department in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Texas Transportation Institute, Texas A&M University, 12 pages (1972).

McCully, W. G., W. J. Bowmer, and J. L. Stubbendieck, "Problems in Establishing or Maintaining Vegetation on Roadsides," Research Report 142-1, Research Project 2-18-69-142, Texas Highway Department in cooperation with the U.S. Department of Transportation, Federal Highway Administration, 18 pages (1970).

McGowan, J. M. B., R. C. Lammasson, and S. S. Salac, "Collection, Propagation, Culture and Evaluation of Plant Materials," Nebraska Research Study 64-2, Interim Report HPR-1(10), University of Nebraska, Nebraska Department of Roads, and U.S. Department of Transportation, Federal Highway Administration, 61 pages (1973).

McKenzie, L. J., and H. Kemmerer, "Illinois Soil Groups Adapted to Short-Growing Woody and Herbaceous Plants Used in Roadside Stabilization and Beautification," Series No. 55, Department of Horticulture, University of Illinois, State of Illinois, Division of Highways, U.S. Department of Commerce, Bureau of Public Roads (1966).

"Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants," U.S. Environmental Protection Agency, Office of Air and Water Programs, EPA 430/9-73-014, 261 pages, October 1973.

"National Atlas of the United States," Geological Survey, U.S. Department of the Interior, Washington, D.C. 20240, 417 pages (1970).

"Natural Vegetation of Oregon and Washington," U.S. Superintendent of Documents, Government Printing Office, 417 pages (1973).

Osborn, J. F., J. Letey, and N. Valoris, "Surfactant Longevity and Wetting Characteristics," In: California Turfgrass Culture, 19(3):17-18, July 1969.

Packer, P. E., and G. F. Christensen, "Guides for Controlling Sediment from Secondary Logging Roads," Forest Service, USDA, 41 pages (1964).

Peck, R. B., W. E. Hanson, and T. H. Thornburn, Foundation Engineering, John Wiley and Sons, 514 pages (1974).

Perkins, A. T., Department of Agronomy, Pennsylvania State University, University Park, Pennsylvania.

"A Pine for Hot Sandhills," In: Forest Farmer, p. 12, June 1974.

"Processes, Procedures, and Methods to Control Pollution Resulting from All Construction Activities," U.S. Environmental Protection Agency, Office of Air and Water Programs, EPA 430/9-73-007, 234 pages, October 1973.

"Processes, Procedures, and Methods to Control Pollution Resulting from Silvicultural Activities," U.S. Environmental Protection Agency, 91 pages (1973).

"Professional Workers in State Agricultural Experiment Stations and Other Cooperating State Institutions, 1972-1973," Agriculture Handbook No. 305, Cooperative State Research Service, USDA, Washington, D.C. 20250, 204 pages, December 1972.

Rosenthal, R. N., "Vegetative Cover for Highway Rights-of-Way," Washington State Highway Commission in cooperation with the Federal Highway Administration, 49 pages (1973).

"Seeding for Erosion Control on Newly Shaped Slopes," USDA Soil Conservation Service, M-2430-225, Portland, Oregon, 3 pages (1969).

"Seeding for Erosion Control on Slopes," USDA Soil Conservation Service, M-2430-233, Portland, Oregon, 2 pages (1970).

Seymour, E. L. D., ed., The Wise Garden Encyclopedia, Grosset and Dunlap, 1380 pages (1970).

Shickluna, J. C., "Sampling Soils," Michigan State University Extension Bulletin E-498, 4 pages (1973).

Sindelar, B. W., "Dryland Sodding with Native Grasses for Permanent Erosion Control," Research Report 43, Montana State University, Montana Department of Highways, and U.S. Department of Transportation, Federal Highway Administration, 22 pages (1973).

"Soil Erosion by Water: Some Measures for its Control on Cultivated Lands," Food and Agriculture, Organization of the United Nations, 284 pages (1965).

"Soil Series of the United States, Puerto Rico, and the Virgin Islands: Their Taxonomic Classification," 361 pages (1972).

"Soil Taxonomy," Soil Survey Staff, Soil Conservation Service, U.S. Department of Agriculture, Preliminary, Abridged edition, 330 pages, October 1973. Note: Interim publication for in-service use, GPA 470-728 2357-72.

"Soil Taxonomy in the United States," This will be published by the Government Printing Office in 8 to 12 months.

"Soils of the Western United States," Regional publication published at Washington State University, 69 pages (1964).

"Soil Testing and Plant Analysis," by L. M. Walsh, and J. D. Beaton, Soil Science Society of America, 491 pages (1973).

"Sources of Native Seeds and Plants," Soil Conservation Society of America, 7515 N.E. Ankeny Road, Ankeny, Iowa 50021, 9 pages, May 1971.

"Standards and Specifications for Soil Erosion and Sediment Control in Urbanizing Areas," Department of Water Resources, State of Maryland and Soil Conservation Service, College Park, Maryland (1969).

Stark, N., "Review of Highway Planting Information Appropriate to Nevada," Desert Research Institute, University of Nevada, Reno, Nevada, in cooperation with the Nevada State Highway Department, College of Agriculture, Bulletin B-7, 209 pages (1966).

Surfactants. A list of companies, with addresses, that sell surfactants is on page E80 of 1974 Farm Chemicals Handbook, Meister Publishing Company, 37841 Euclid Avenue, Willoughby, Ohio 44094.

Tennille, A. W., and A. J. Langlois, "Selection of Woody Plants to be Used for Highway Landscaping and Erosion Control," Highway Research Project 22, Arkansas State University, Arkansas State Highway Department and U.S. Department of Transportation, Federal Highway Administration, 43 pages and appendix (1971).

Thompson, L. M., and F. R. Troeh, Soils and Soil Fertility, McGraw-Hill Book Company, 495 pages (1973).

"Two-Thirds of Our Land: A National Inventory," Soil Conservation Service, USDA, Washington, D.C., Program Aid No. 984, 19 pages (1971).

Waddington, D. V., Department of Agronomy, Pennsylvania State University, University Park, Pennsylvania 61801.

Walsh, L. M., and J. D. Beaton, editors, "Soil Testing and Plant Analysis," Soil Science Society of America, 491 pages (1973).

Ward, C. Y., Department of Agronomy, Mississippi State University, State College, Mississippi 39723.

"Water-Repellant Soils," Proceedings held at the University of California at Riverside, 354 pages, 6-10 May 1968 (published 1969).

"Watershed Tillage - 7412," U.S. Department of the Interior, Bureau of Land Management, Manual Transmittal Sheet, 7 November 1968.

"Wetting Agents for Erosion Control on Burned Watersheds," by N. Valoris, J. F. Osborn, and J. Letey, California Agriculture, pp. 12-13, May 1974.

Whitaker, S. E., "Establishment of Woody Plants on Roadsides (Southeastern Kentucky)," Research Report 304, Department of Highways, Commonwealth of Kentucky in cooperation with the U.S. Department of Transportation, Federal Highway Administration, 27 pages and appendix (1971).

White, D. B., and T. B. Bailey, "Vegetation Maintenance Practices, Programs and Equipment on Minnesota Highways," Investigation No. 619, University of Minnesota, Minnesota Department of Highways, U.S. Department of Transportation, and Minnesota Local Road Research Board, 69 pages (1969).

White, D. P., and G. Schneider, "Soilless Container System Developed for Growing Conifer Seedlings," Tree Planters' Notes, 23(1):1-5, February 1972.

"Wildland Soils, Vegetation, and Activities Affecting Water Quality," California Department of Conservation, Division of Forestry, paged by sections totaling 1004, August 1972.

Winkelaar, P., "Forest Road Location and Erosion Control on Northern New Hampshire Soils," Extension Publication No. 2, Cooperative Extension Service, University of New Hampshire, Durham, New Hampshire, in cooperation with White Mountain National Forest, USDA Forest Service, 18 pages, August 1971.

Winkworth, R., 1974 President of the National Association of State Foresters, Raleigh, North Carolina.

Woodruff, J. M., and R. E. Blaser, "Stabilizing Disturbed Areas During Highway Construction for Pollution Control," HPR Code 0754, Virginia Polytechnic Institute and State University, Virginia Department of Highways, U.S. Department of Transportation, Federal Highway Administration, 86 pages (1971).

Wyant, D.C., W. C. Sherwood, and H. N. Walker, "Erosion Prevention During Highway Construction by the Use of Sprayed-on Chemicals," Virginia Highway Research Council, Virginia Department of Highways, University of Virginia, and U.S. Department of Transportation, Federal Highway Administration.

VI. ADDITIONAL CONTRIBUTORS

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VI. ADDITIONAL CONTRIBUTORS

A. General

The Environmental Protection Agency also acknowledges substantial assistance from the following contributors.

Victor Barry, Jr.
Division of Plant Sciences
SCS, USDA
Washington, D.C.

Lindo J. Bartelli
Soil Survey Interpretations
USDA
Washington, D.C.

Richard Brammer
State Highway Department
Santa Fe, New Mexico

J. E. Burford
Hydrologic Data Laboratory ARS/USDA
Beltsville, Maryland

John Creech
National Arboretum
Washington, D.C.

Euel Davis
Division of Watersheds
Bureau of Land Management
Washington, D.C.

George Edmundson
SCS Plant Material Center
Lockeford, California

Dick Howell and Roger Hallin
California Department of Transportation
(CALTRANS)
Sacramento, California

Gordon Huntington
University of California at Davis
Davis, California

D. Earl Jones
Arlington, Virginia, Department of
Housing and Urban Development
Washington, D.C.

Kermit N. Larson
U.S. Forest Service
Odgen, Utah

Andrew T. Leiser
Department of Environmental Horticulture
University of California at Davis
Davis, California

John E. McClelland
Soil Survey Operations,
SCS, USDA
Washington, D.C.

Wayne McCully
Extension and Research Center
Vernon, Texas

Walter Megahan
Intermountain Forest and Range Research
Station
Boise, Idaho

William W. Mitchell
Institute of Agricultural Sciences
Palmer Research Center
Palmer, Alaska

Douglas L. Smith
Environmental Design and Control Division
Office of Research
Federal Highway Administration
Washington, D.C.

Grant W. Thomas
University of Kentucky
Lexington, Kentucky

H. B. Vanderford
Mississippi State University
State College, Mississippi

Dirk van der Voet
Soil Conservation Service
Washington, D.C.

William Wertz
U.S. Forest Service
Washington, D.C.

Leonard Wood, Chief
Environmental Control Group
Federal Highway Administration
Washington, D.C.

James A. Yost
J. B. Gilbert and Associates
South Lake Tahoe, California

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St. Joseph, Michigan

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U.S. Department of the Interior
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U.S. Forest Service
Upper Darby, Pennsylvania

Southeast Environmental Research
Laboratory, EPA
Athens, Georgia

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Tennessee Valley Authority
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U.S. Forest Service, Rocky Mountain Forest
and Range Experiment Station
Fort Collins, Colorado

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Washington, D.C.

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E. Private Firms

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2.

W

Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities

5. Report Date

6.

8. Performing Organization Report No.

Francis Wm. Bennett and Roy L. Donahue

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

68-01-2632

13. Type of Report and Period Covered

Sponsoring Organization

The study has produced a user's manual for the 50 states on latest methods and procedures for establishing dense stands of perennial vegetation on soils of low productivity that have been disturbed by construction activities, will hold the soil in place and thus minimize water pollution by sedimentation. The 450 page manual has defined common ground, in a practical and applied way, among many technical disciplines. The sciences of soil, geologic material and plant growth are defined and related. Emphasis of the manual is on vegetating soils that naturally are low in productivity. Soil Great Groups that fit this criteria representing 39% of the United States land area are discussed. The soil and plant research of many professional scientists are related and brought into focus. Demonstration sites at 10 locations are characterized and documented.

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